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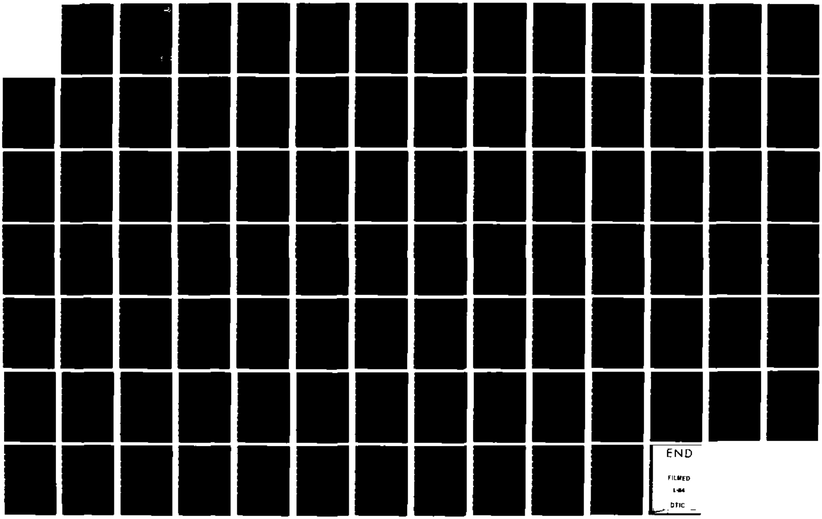

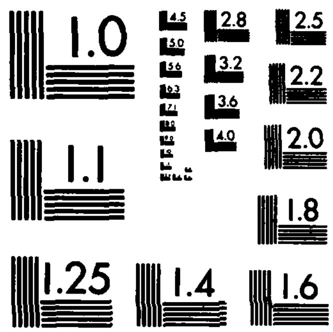

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INTEGRATING MULTI-OBJECTIVE OPTIMIZATION METHODOLOGIES IN BMD TECHNOLOGY

BY

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FOREWORD

This report represents work performed by the Management Science and Statistics Department of the University of Alabama, University, Alabama, while under contract to the Ballistic Missile Defense Advanced Technology Center. Technical contact for this effort was Mr. Walter L. Dixon, Jr.

ABSTRACT

This technical report describes a microprocessor version of a threat allocation model based on simple decision heuristics. Model capability is demonstrated by allocating a threat composed of four

reentry vehicles

r.v. systems over four categories of assets using different asset defense schemes. Allocations obtained with the heuristic model compare favorably with allocations obtained with a much more sophisticated model.

The report also describes a generalized R&D project network simulation model which provides reliable estimates for project start and completion times, project duration times, and failure statistics. The simulation model is demonstrated with a complex network composed of six individual, interdependent projects.

The report includes as an appendix a paper describing a mathematical optimization approach to threat allocation decisions that was presented at the national ORSA/TIMS meetings in October 1982.

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SECTION I

INTRODUCTION

The research described in this report was conducted as three separate projects and is reported here in separate sections. A major emphasis of the research was to develop a simple, heuristic algorithm for the threat allocation decision which could be executed on a microprocessor; the results of this effort are described in Section II. A secondary emphasis of the research was to develop a generalized R&D network simulator for use in project planning and management; results of this phase of the effort are described in Section III. Finally, a part of the research effort was expended in documenting an earlier version of the threat allocation model for presentation at the national ORSA/TIMS meetings; the resulting paper is discussed in Section IV.

SECTION II

THREAT ALLOCATION MODEL

2.1 Threat Allocation Decision

One of the major tasks faced by the military planner in specifying defense mission requirements is assessing the nature of the threat which must be countered. With respect to BMD mission analysis, the analyst must determine how an assumed threat would likely be targeted against assets of importance and what the resulting damage would be. This problem has been treated with threat allocation models which "allocate" the threat over the assets in such a way as to achieve some explicitly stated objective, e.g., maximization of value of assets destroyed. An example of this type of threat allocation model is shown in Appendix X.

This research had as one of its objectives the development of a threat allocation model which would differ from existing models in two major respects. First, the allocation logic would be based on simple decision heuristics rather than optimization or enumeration algorithms. Second, the procedure would be developed for running on a microprocessor rather than a large mainframe computer. The resulting model incorporates rather straightforward logic which closely replicates military strategy and it has been run on an Apple II using Apple BASIC.

The research is presented in three parts. The first part describes the heuristics upon which the program is based. Some examples of the application of the model are described in the second part of the discussion. The final part of the discussion is a critique of the model.

2.2 Allocation Heuristics

In attempting to more realistically model the threat allocation decision, consideration was given to incorporating a "threat strategy" into the decision logic. Once the threat strategy has been defined, allocations are made on the basis of a simple allocation rule.

2.2.1 Threat Strategy

The threat strategy defines military objectives of the threatening force which are to be achieved in actual operations. Included are kill priorities, kill criteria, and kill objectives.

2.2.1.1 Kill Priorities. Each asset is assigned a priority corresponding to the importance attached to it by military planners of the threatening force. For example, if a major objective of the strike is to achieve air superiority, air bases would be assigned a kill priority of 1.

2.2.1.2 Kill Criteria. Each asset is assigned a kill criterion corresponding to the degree of certainty the threatening force wishes to achieve in destroying the asset. For example, the threatening force might wish to be 99 percent certain that air bases are destroyed, whereas a 90 percent assurance may be acceptable for other assets. Then, in making allocations, sufficient r.v.'s must be targeted to airbases to assure that the combined kill probability equals or exceeds .99.

2.2.1.3 Kill Objectives. Each class of assets is assigned a kill objective corresponding to the percentage of assets in the class which

the threat should successfully destroy. For example, it may be necessary to destroy 95 percent of the airbases to achieve air superiority.

2.2.2 Allocation Rule

Once the threat strategy is defined, it is a relatively simple matter to search the asset list in kill priority sequence assigning r.v.'s to each asset in a particular asset category until the required percent of assets in that category is destroyed with probability equal to or greater than the required kill criterion for the asset. All that remains to completely define the allocation procedure is to specify the rule for assigning r.v.'s to assets. The rule followed in the procedure described here is to assign from available r.v.'s the one having the minimum P_{SSK} for the asset being considered.

2.2.3 Allocation Procedure

A complete description of terminology and notation used in the allocation model is contained in Appendix I. A detailed narrative of the allocation logic is presented in Appendix II with a flowchart of the logic in Appendix III. A listing of the BASIC computer program developed appears in Appendix IV.

2.3 Model Applications

To demonstrate the use of the model in threat allocation decisions, a hypothetical problem described in a paper presented at the national ORSA/TIMS meeting is used. The paper which is included as Appendix X describes a tactical situation involving four asset types and four r.v. systems. The threat definition for this problem is shown in Table 1 of

the Appendix, the asset structure is given in Table 2, and single shot kill probabilities are from Table 3.

2.3.1 No Defense Scenario

The first scenario assessed with the heuristic model was a no defense case in which all assets in each of the four categories were unprotected. Sample output for the no defense case is given in Ar ›ndix V. From the echo report of input data, it may be seen that the ε ›ts are ranked in descending order by kill priority with type 1 asset ranked first and type 4 assets ranked last. Notice also that the criterion for type 1 assets is .99 while .90 is specified for other assets. Furthermore, the kill objective for each asset category is .95. Each of the r.v. systems in the illustration has a reliability/ availability factor of .90.

The allocation model commits a total of 75 type 1 r.v.'s to type 1 assets destroying all 15 assets. The remaining type 1 r.v.'s are targeted to type 2 assets as are all of the type 3 and 4 r.v.'s, thus destroying 15 of the 45 type 2 assets. Note from the output that no assets of type 3 or 4 are killed and that none of the type 2 r.v.'s are allocated. This is obviously a shortcoming of the allocation heuristic and will be mentioned subsequently.

2.3.2 Defense Scenarios

Several scenarios were assessed varying the defense assigned to each of the assets. In all cases, interceptors were assigned uniformly to the assets and the probability of successful intercept was assumed to be .90. From Appendix V it may be seen that when one interceptor is assigned to each asset, <u>all</u> available type 1 r.v.'s must be committed to

type 1 assets in order to destroy all 15 of the assets. All available type 3 and 4 r.v.'s are allocated to type 2 assets destroying 13 of the 45 assets. Table 2.1 shows the effect of the number of interceptors committed to each asset on the number of assets destroyed. Assigning one interceptor to each asset essentially buys two type 2 assets. Assigning two interceptors to each asset buys one type 1 asset (rather than allocating r.v.'s to all 15 type 1 assets, the model targets only 14 which satisfies the kill objective for that category). When four interceptors are assigned to each asset, the model begins to target type 2 r.v.'s to type 2 assets. The last defense scenario considered was to assign eight interceptors to each asset; from Table 2.1 it may be seen that the results are the same as when four interceptors are assigned -- the only difference is that a greater number of type 2 r.v.'s is required.

2.4 Model Critique

Limited experience with the heuristic model to date suggests that results compare favorably with results obtained using more sophisticated algorithms. For example, if the no defense allocation results in terms of assets destroyed are valued using the asset values reflected in Table 2 of Appendix X, approximately 49 percent of the total value of the assets would be destroyed. Referring to Figure 4 of Appendix X, it may be seen that roughly the same percentage value of assets would be destroyed by the allocation model used in that study (at the 1.0 Threat Level).

Table 2.1. Effect of Defense Options on Number of Assets Destroyed

Number of Interceptors Per Asset	Number of Assets Destroyed			
	Type 1	Type 2	Type 3	Type 4
0	15	15	0	0
1	15	13	0	0
2	14	13	0	0
4	14	13	0	0
8	14	13	0	0

The model appears to have enough potential to warrant further examination with a view toward enhancement. For instance, integrating second order heuristics may overcome the shortcoming mentioned earlier. If r.v.'s remained unused after the first allocation pass, perhaps a second pass with adjusted P_{SSK} values could yield an improved allocation. Or perhaps a procedure similar to Vogel's Approximation Method used in transportation problems could be used to locate efficient allocations. A number of simple heuristics appear to have application in this regard.

SECTION III

R&D PROJECT PLANNING NETWORK SIMULATION

3.1 R&D Project Planning

One of the most difficult tasks in project management in an R&D environment is activity scheduling including the related task of estimating duration, start, and completion times for individual activities and entire projects. The task is complicated by the inherent uncertainty associated with R&D activity and by the interdependencies which exist between activities and projects. Project scheduling problems have traditionally been treated with PERT/CPM techniques; however because of the high levels of inherent uncertainty, attention has been focussed on simulation models as a way of providing the time estimates needed to effectively manage R&D efforts.

Unfortunately, one of the frequently cited limitations of simulation is that it is not sufficiently flexible (or general) to be of much use in a dynamic environment. There does appear to be a legitimate need for a project network simulator that is sufficiently general to be applicable to the majority of R&D cases. Thus, one of the emphases of this research was to develop a generalized project network simulator which could be easily adapted to model a variety of R&D network situations.

The research is discussed in three parts. The first part presents a general R&D network representation. The network simulation model is described in the second part of the discussion along with data inputs required and outputs generated by the model. The final part of the discussion is a critique of the network simulator.

3.2 R&D Project Networks

In order to develop a generalized R&D network simulator, it is first necessary to specify a framework which can be used to represent a variety of R&D projects. The framework devised in this research is a generalized project activity representation which can itself be networked to represent complex R&D projects.

3.2.1 Individual Project Representation

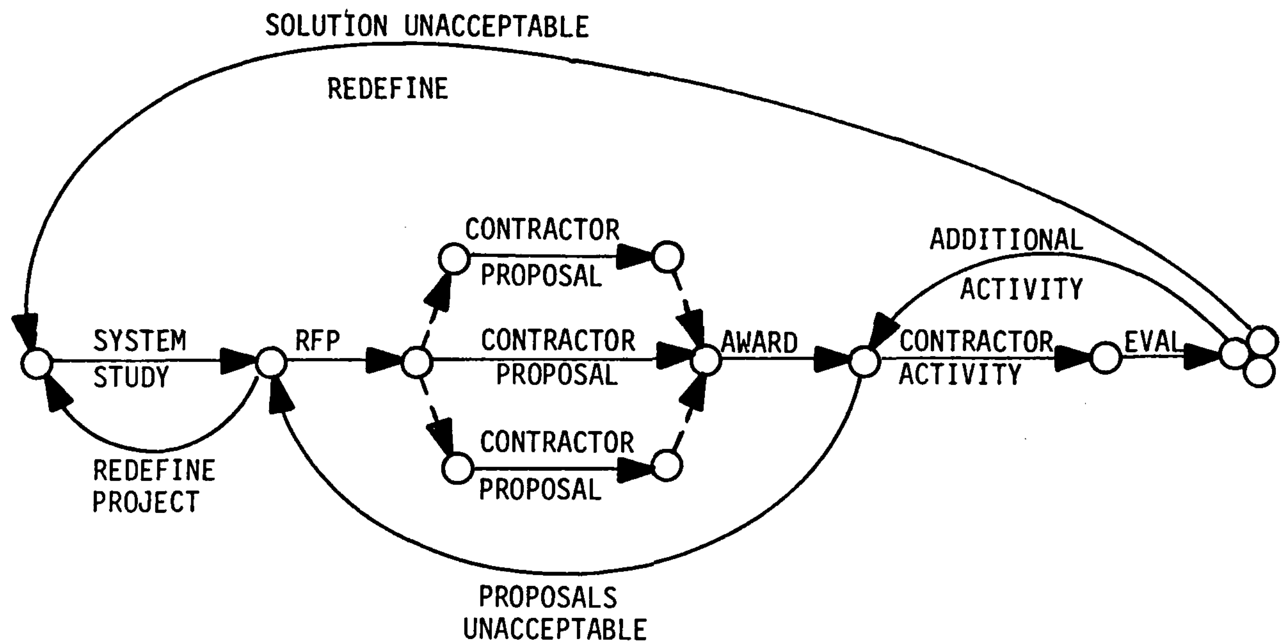
Figure 3.1 shows the individual project network representation. In developing this framework, an attempt was made to include every activity which could occur in an R&D project. The main activity sequence is from left to right and includes the following distinct activities:

- System Study. Activities related to definition of project objectives/requirements.
- RFP. Preparation and distribution of requests for proposal.
- Contractor Proposal. Activities undertaken by contractors in response to the RFP.
- Award. Assessment and evaluation of various contractor proposals and award of contract.
- Contractor Activity. Actual research and development effort by contractor as required by contract.
- Evaluation. Evaluation of contractor effort with respect to project objectives/requirements.

In addition to these major activities, the network contains four restart loops which correspond to unsuccessful activity of one form or another. The four loops are:

- Redefine Project. A redefinition of the project might be required for a variety of reasons including: budget considerations, technology limitations, etc.

Figure 3.1. Generalized Network for R&D Project Activity.



- Proposals Unacceptable. The RFP phase may have to be repeated due to inadequate project specification, budget considerations, contractor problems, etc.
- Additional Activity. After the contract evaluation, the contractor may be required to undertake additional activity to complete the contract.
- Solution Unacceptable. Alternatively, the evaluation may show that the effort failed with respect to objectives and that a new effort is required.

3.2.2 A Generalized Network

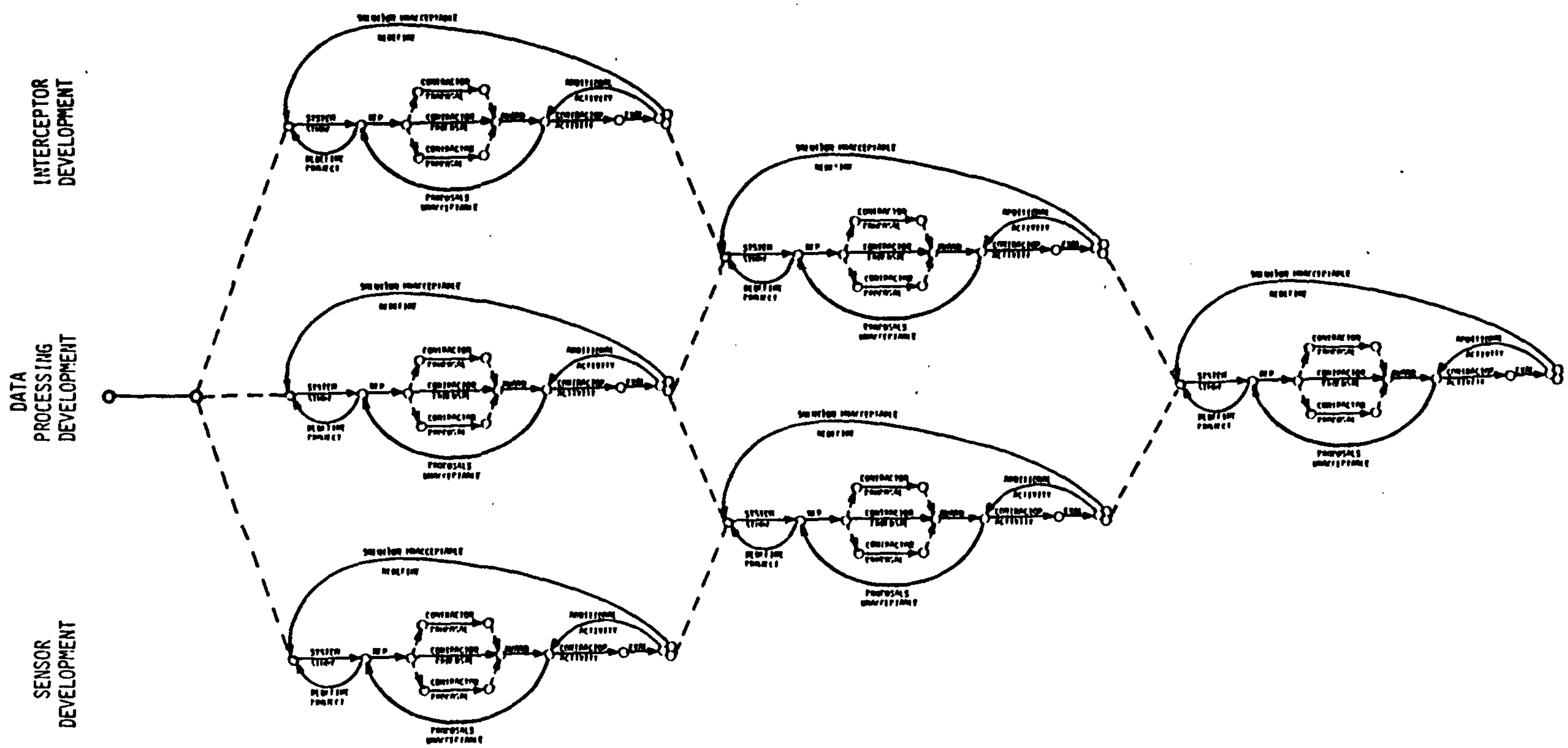
Figure 3.2 shows a complex network composed of six individual project networks of the form described in the previous paragraph. The particular network shown includes individual interceptor, data processing, and sensor projects which must be integrated in follow-on projects in order to complete the complex development represented by the composite network.

It should be noted that individual project networks can be combined in whatever way is necessary in order to represent the interdependencies inherent in a complex R&D effort. Such complex efforts routinely involve literally scores of individual projects.

3.3 Network Simulator

A UNIVAC 1100 GPSS simulation model of the network shown in Figure 3.2 was written and run to produce 1,000 replications of the complex project. Terminology and notation incorporated in the model are shown in Appendix VI, program logic is detailed in Appendix VII, and a flowchart of model logic appears in Appendix VIII.

Figure 3.2. A Generalized Complex Network of R&D Projects.



3.3.1 GPSS Program

The GPSS program includes three major sections. The first section is primarily definitional and includes a matrix named VAL(I,J) which is used to input mean activity times and modifiers, probability values for unsuccessful activities, and precedence relationships. Each row in the matrix represents an individual project; columns are as defined in statement numbers 41-63 of the program listing. The second section of the program models the actual sequence of activities from system study through contract evaluation -- statement numbers 83-152. The last segment of the program is used for collecting statistics of interest to project management.

Use of a matrix for inputting project descriptive data makes it extremely easy to change these values for "what if" analysis. It is not necessary to make changes to statements within the program. All that is required is to make appropriate changes to the matrix INITIAL statements, statement numbers 65-77.

3.3.2 Simulator Output

Standard GPSS output for this model is fairly extensive amounting to about eight pages; furthermore the output is difficult to understand without a thorough knowledge of GPSS. For this reason a FORTRAN report generator was linked to the simulator via the GPSS HELP statement. Important GPSS output is summarized in a report which should communicate to project managers having little familiarity with simulation; an example is shown on page 57. The report gives project start and completion times, project durations, and statistics on failures. For example, for the six project network depicted in Figure 3.2, the final

project (project six) would commence 1,493 time units from the start date and would be completed 2,167 time units from the start date. Out of 1,000 replications of project 6, the system study phase had to be redone 4 times, the contractor had to perform additional work 9 times, and the entire project failed once.

3.4 Model Critique

The value to project managers of the kind of information available from the simulator should be obvious. Project scheduling could be done with greater accuracy because of the availability of reliable time estimates. Various scenarios could easily be assessed by changing input data and rerunning the simulation. The simulator is limited in at least two respects. First, the output will only be as good as the input data; some of the probability estimates and activity duration times may be difficult to obtain especially when no prior R&D experience exists. Second, to change the network formats presented in Figure 3.1 and 3.2 would require changing the GPSS program, a task which would require expert programming capability.

SECTION IV

A THREAT ALLOCATION MODEL FOR TACTICAL WARFARE

A final task of the research was to document an earlier version of the threat allocation model for presentation at the ORSA/TIMS Joint National Meeting in San Diego, California, October 25-27, 1982. The paper presented at the conference is included in its entirety in Appendix X.

APPENDIX I

TERMINOLOGY AND NOTATION USED IN THREAT ALLOCATION PROGRAM

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TERMINOLOGY AND NOTATION USED IN THREAT ALLOCATION PROGRAM

Program Notation	Standard BMD Notation	Definition
T	I	The number of asset types, i=1, 2, ..., m
H	J	The number of reentry vehicle types, j=1, 2, ..., n
P(T,H)	P_{ij}	The probability of killing a type i asset with a single reentry vehicle of type j
A(T)	A_i	The number of type i assets available
Y(T)	Y_i	The kill criteria for asset type i
R(T)	R_i	The kill priority for asset type i
O(T)	O_i	The kill objective for asset type i
B(H)	B_j	The number of type j reentry vehicles available
Q(H)	Q_j	The name of asset type i
U$(T)		The name of asset type i
NN(T)	N_i	The number of interceptors available to defend asset type i
II(T)	P_{ki}	The probability that a terminal interceptor kills a reentry vehicle attacking asset i
V	X_{ij}	The number of type j reentry vehicles that must be allocated to each asset of type i
E		For a selected asset, E is the highest single shot kill probability given the j type reentry vehicle available
W		A counter which indicates the number of complete allocations made
R		Index number used as a starting point in the search for the asset type with the highest kill priority

APPENDIX I

(CONTINUED)

Program Notation	Standard BMD Notation	Definition
C		An intermediate index used to arrive at the final reentry vehicle allocation
U		The intermediate probability of survival for the selected asset type
X		The aggregate kill probability for asset type i given the allocation of C number of j type reentry vehicles
S		The number of random variables to be allocated to each asset of type i if the number of reentry vehicles is not sufficient to lead to a complete destruction of that asset

APPENDIX II

THREAT ALLOCATION LOGIC

APPENDIX II

THREAT ALLOCATION LOGIC

1. Block 1. Read input data:

   NN(T), II(T), U$(T), P(T,H), A(T), Y(T), R(T), O(T),

   B(H) and Q(H) for T=1, 2, ..., I and H=1, 2, ..., J

2. Blocks 2-4. Compute desired kill objective for each asset type and integerize the result

   A(T) = Int[A(T) * O(T) + .99] for T=1, 2, ..., I

3. Blocks 5-9. Adjust the single shot kill probabilities for each reentry vehicle type to reflect the reliability/availability factor of that random variable

   P(T,H) = P(T,H) * Q(J) for T=1, 2, ..., I and H=1, 2, ..., J

4. Block 10. Set W = 1 marking the start of the allocation algorithm. W will be incremented by one whenever an asset is chosen for an allocation. Set R = 999 which will serve as a starting search point for the next step.

5. Blocks 11-14. Select the asset with the highest kill priority (where 1 indicates the highest kill priority).

6. Block 15. Set E = -999 which will serve as a starting search point for the next step.

7. Blocks 16-19. For the asset selected in step 5, select the reentry vehicle that has the highest single shot kill probability.

APPENDIX II

(CONTINUED)

8. Block 20. For defended assets, the single shot kill probability is adjusted to account for the interceptor's defense.

$$TR = E * (1 - II(A))$$

9. Blocks 21-29. Determine min C for which

$$1 - [(1 - TR)^{NN(A)} * (1 - E)^{C-NN(A)}] \geq Y(A)$$

10. Block 30. Set V = C where V is the minimum number of reentry vehicles to be allocated to the selected asset.

11. Block 31. Determine if there is a sufficient number of the selected reentry vehicle to destroy the selected asset.

12. Blocks 32, 44-54. If there is a sufficient number of the selected reentry vehicles then that number should be reduced by the number needed to destroy the selected asset (Block 32). Then the allocations determined in steps 9 and 10 are printed (Blocks 44-47) and the asset single shot kill probabilities are deleted (Blocks 48-50) since no more allocations will be made to that asset. The asset is then given an extremely low kill priority (R(A) = 999) so that it will not be considered for any further allocations (Block 51). If the number of complete allocations (those allocations that lead to the total destruction of a selected asset) is equal to the number of asset types available the program stops, otherwise the program goes back to step 5 (Blocks 52-54).

APPENDIX II

(CONTINUED)

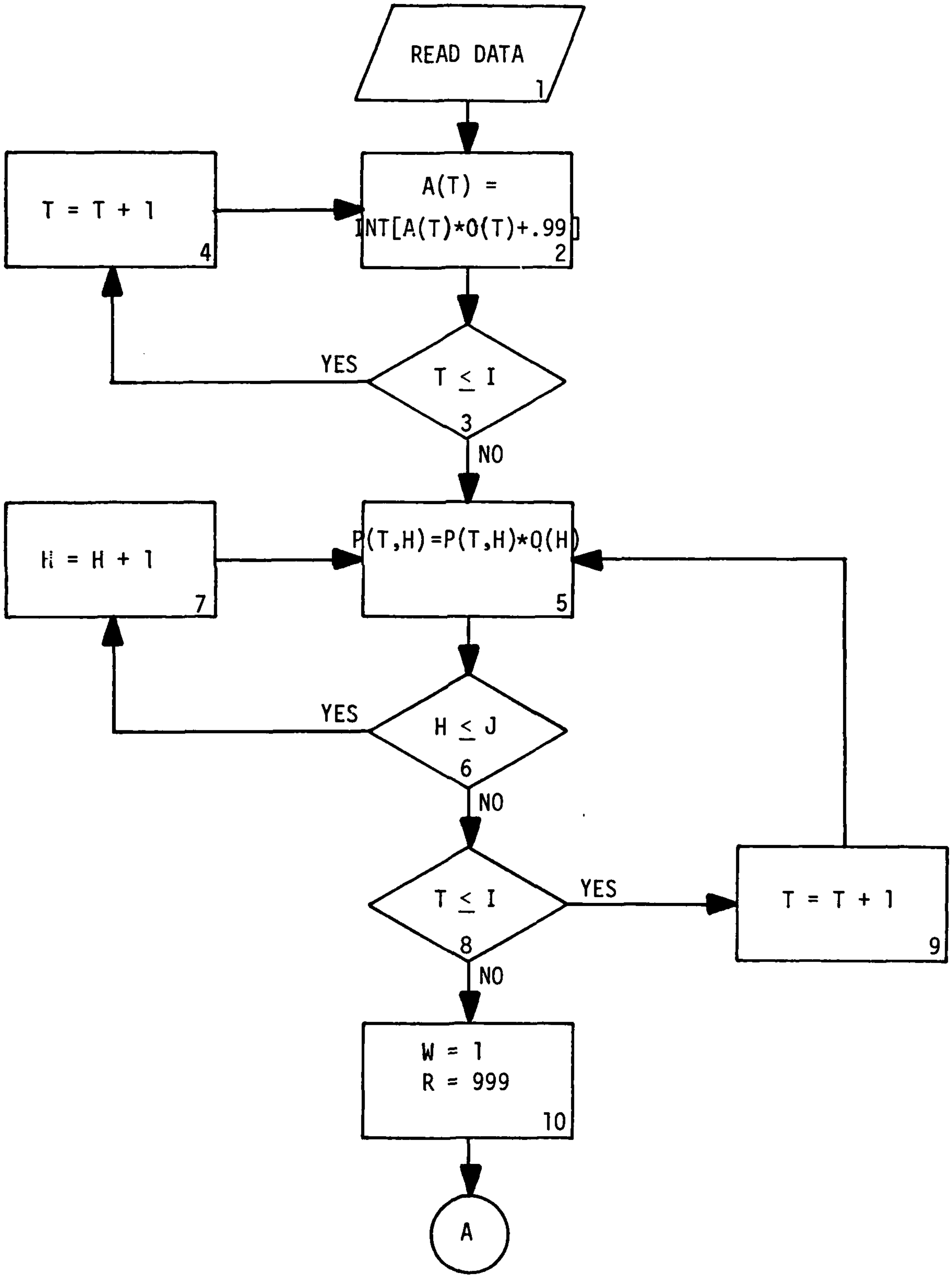
13. Blocks 33-35, 40-43. If the number of reentry vehicles is not sufficient to destroy the selected asset then the available number of reentry vehicles is exhausted to destroy as many as possible of the selected asset type (Blocks 33, 34). The number of assets available is then reduced by the number that has been destroyed, the number of reentry vehicles is set equal to zero, and the allocations are then printed (Blocks 35, 40). The reentry vehicle single shot kill probabilities are then set to zero. Since this reentry vehicle can not be used for any further allocations (Blocks 41, 42, 43), the program then returns to step 6.

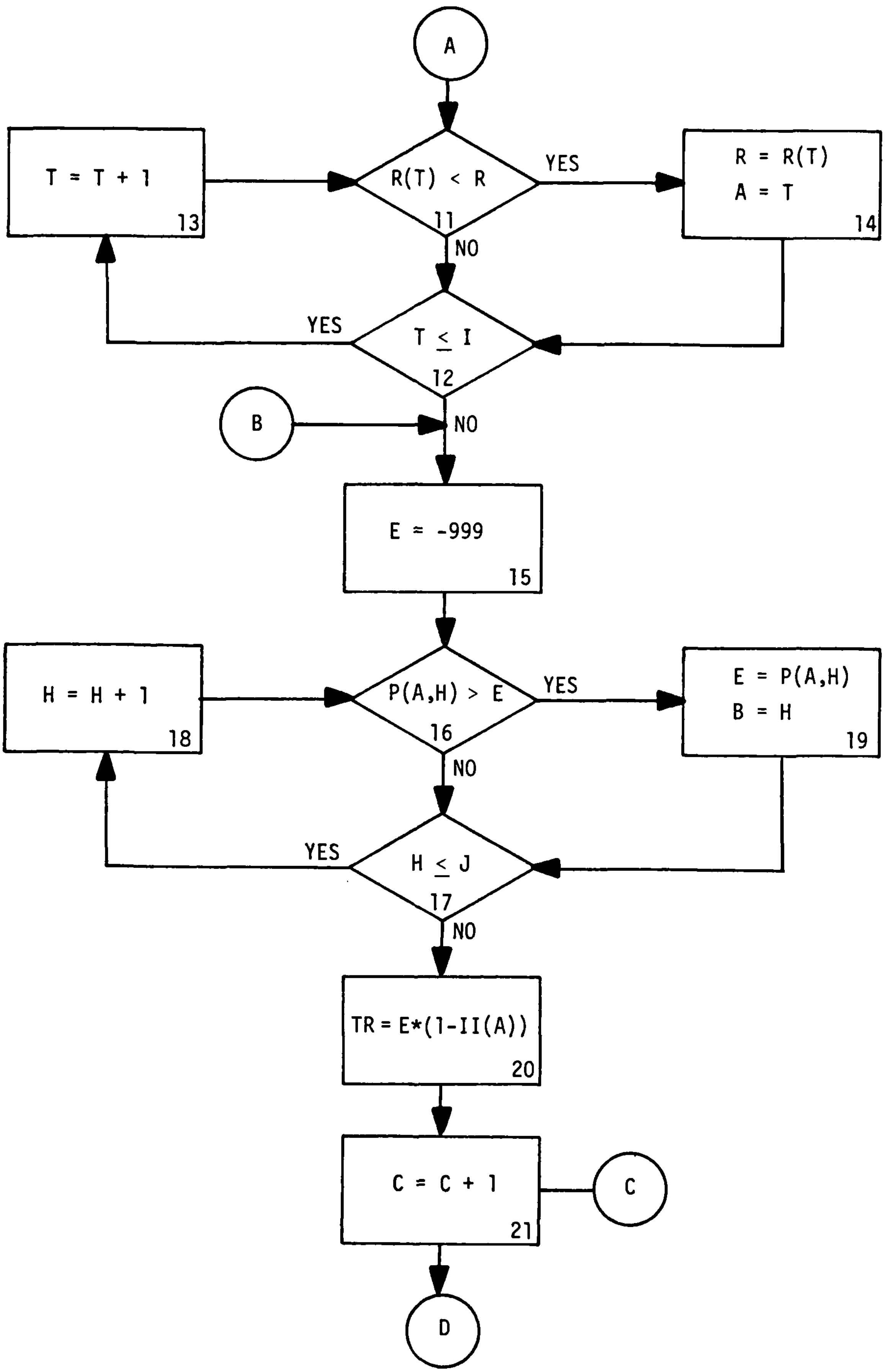
APPENDIX III

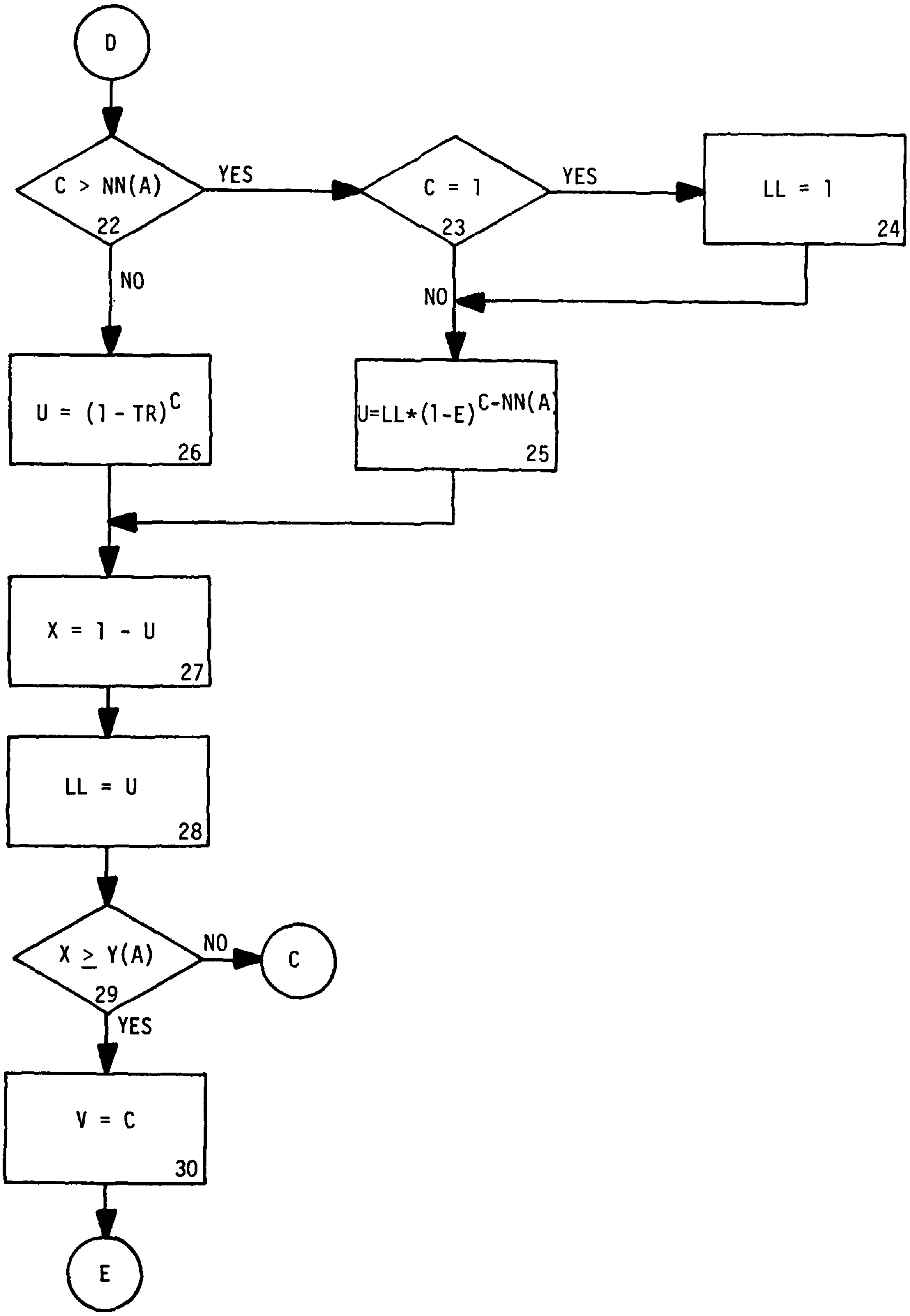
THREAT ALLOCATION PROGRAM FLOWCHART

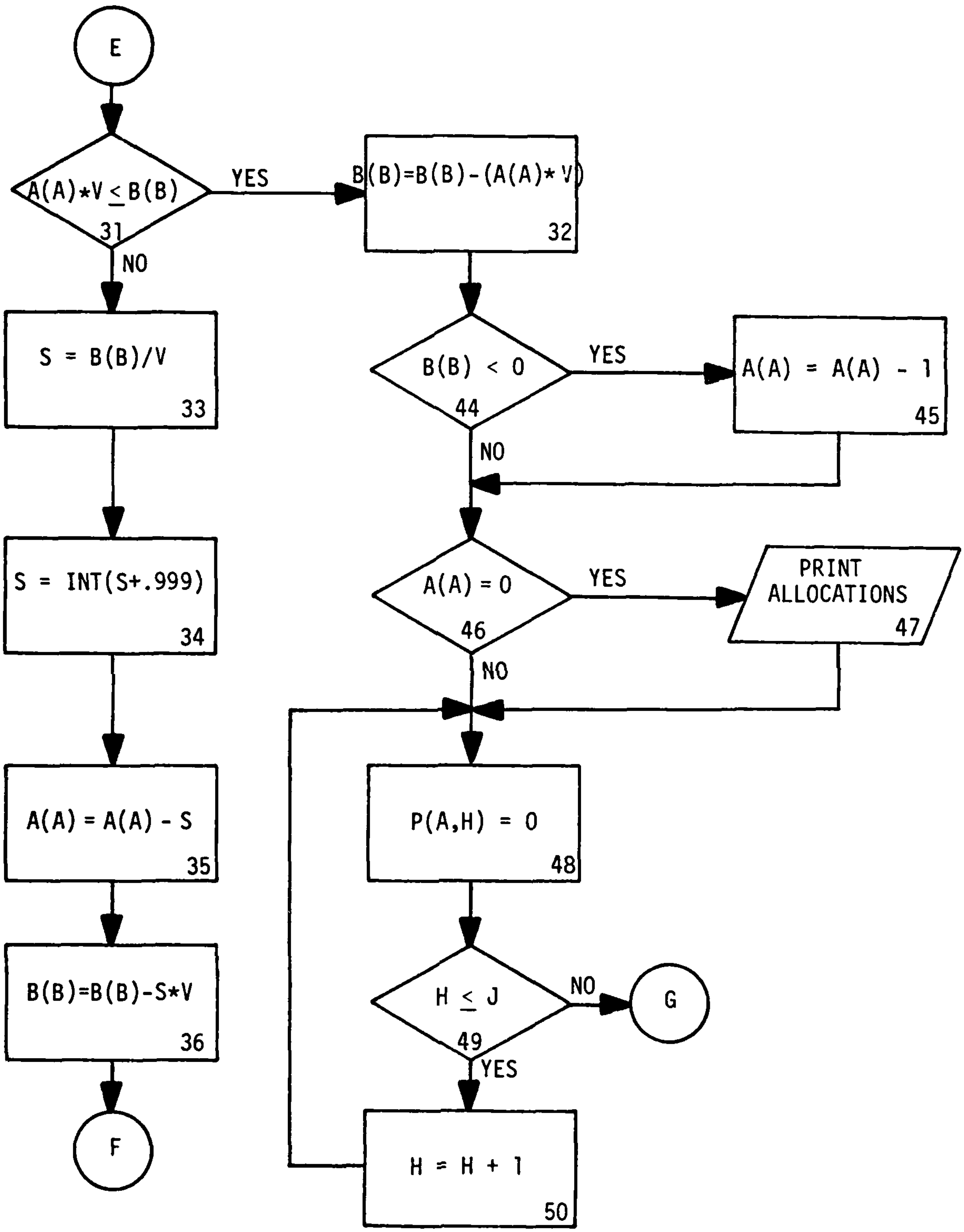
APPENDIX III

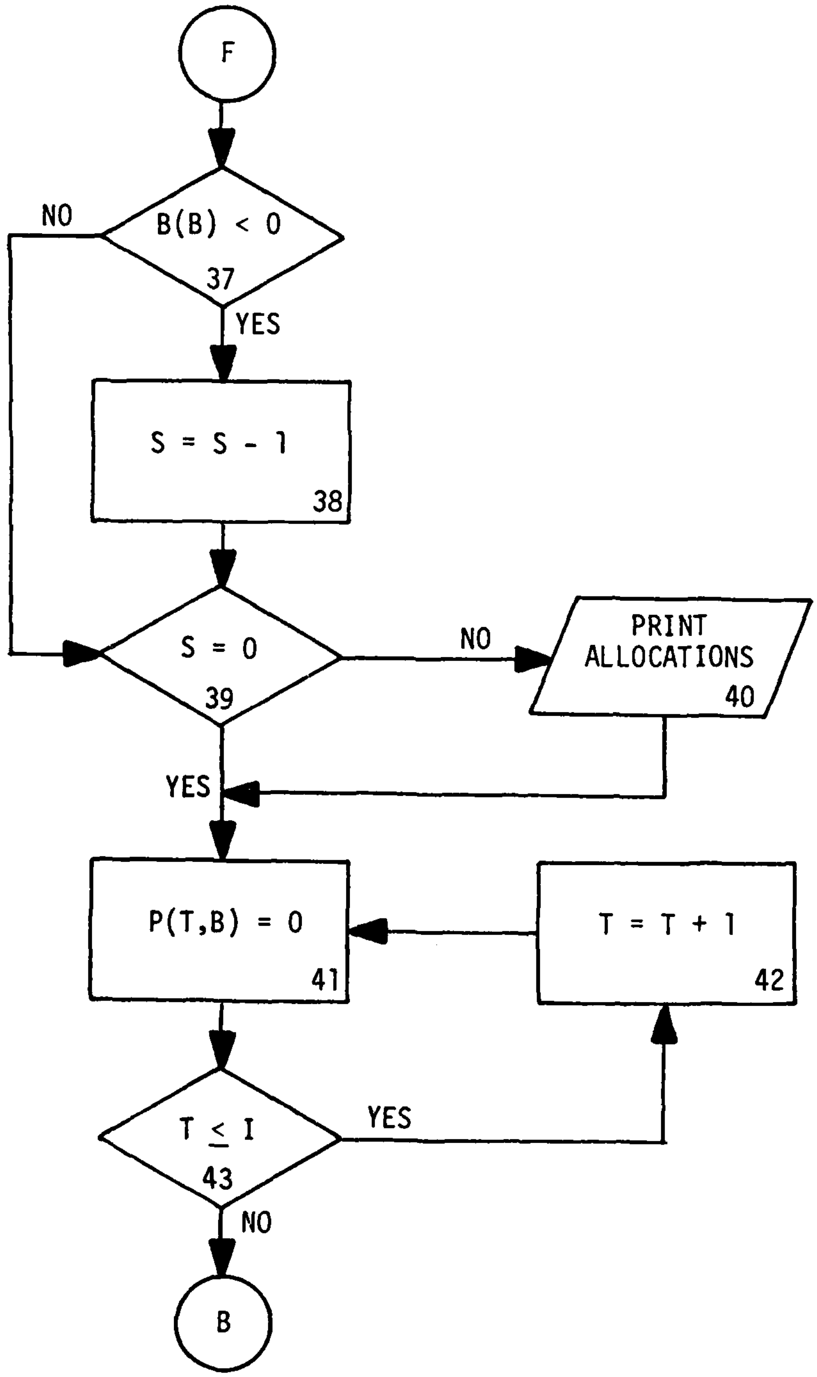
THREAT ALLOCATION PROGRAM FLOWCHART

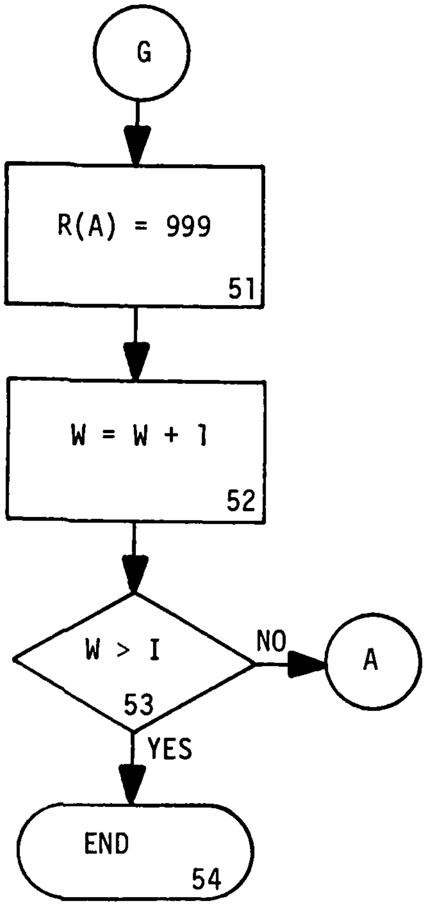



A
R(T) < R
11
YES
R = R(T)
A = T
14
T = T + 1
13
NO
T ≤ I
12
YES
B
NO
E = -999
15
P(A,H) > E
16
YES
E = P(A,H)
B = H
19
H = H + 1
18
NO
H ≤ J
17
YES
NO
TR = E*(1-II(A))
20
C = C + 1
21
C
D


D
C > NN(A)
22
YES
C = 1
23
YES
LL = 1
24
NO
NO
U = (1 - TR)^C
26
U=LL*(1-E)^C-NN(A)
25
X = 1 - U
27
LL = U
28
X ≥ Y(A)
29
NO
C
YES
V = C
30
E


E
A(A)*V ≤ B(B)
31
YES
NO
B(B)=B(B)-(A(A)*V)
32
S = B(B)/V
33
B(B) < 0
44
YES
NO
A(A) = A(A) - 1
45
S = INT(S+.999)
34
A(A) = 0
46
YES
NO
PRINT
ALLOCATIONS
47
A(A) = A(A) - S
35
P(A,H) = 0
48
B(B)=B(B)-S*V
36
H ≤ J
49
NO
YES
G
F
H = H + 1
50


F
B(B) < 0
37
NO
YES
S = S - 1
38
S = 0
39
NO
PRINT ALLOCATIONS
40
YES
P(T,B) = 0
41
T = T + 1
42
T ≤ I
43
YES
NO
B


G
R(A) = 999
51
W = W + 1
52
W > I
53
NO
A
YES
END
54

APPENDIX IV

THREAT ALLOCATION
PROGRAM LISTING

```
]LIST
2  HOME : PRINT " ": PRINT "                                    ** THREAT ALLOCATION
     DEL **": PRINT " ": PRINT " "
4 I = 10:J = 4
5  PRINT : PRINT : PRINT " RUN DESCRIPTION:": PRINT " "
6  PRINT "      ORSA/TIMS: NO DEFENSE ": PRINT " ": PRINT " "
25  PRINT : PRINT : PRINT " INPUTS: ": PRINT " "
26  PRINT : PRINT : PRINT " 1. KILL PROBABILITIES"
27  PRINT : PRINT "                                   REENTRY VEHICLE": PRINT "
28  PRINT " ASSET/ZONE       1                   2                   3
       4"
30  DIM P(I,J): DIM A(I): DIM Y(I): DIM R(I): DIM O(I): DIM B(J): DIM Q(
     : DIM U$(I): DIM NN(I): DIM II(I)
32  FOR T = 1 TO I: READ NN(T): NEXT
33  FOR T = 1 TO I: READ II(T): NEXT
35  FOR T = 1 TO I: READ U$(T): NEXT
40  FOR T = 1 TO I
42  FOR H = 1 TO J
44  READ P(T,H)
46  NEXT
48  NEXT
50  FOR T = 1 TO I
51  PRINT "     ";U$(T);"  ",
52  FOR H = 1 TO J
53  PRINT P(T,H),
54  NEXT
55  PRINT
56  NEXT
58  PRINT " "
90  FOR T = 1 TO I
100  READ A(T)
110  NEXT
120  FOR T = 1 TO I
130  READ Y(T)
140  NEXT
150  FOR T = 1 TO I
153  READ R(T)
157  NEXT
160  FOR T = 1 TO I
170  READ O(T)
180  NEXT
190  FOR H = 1 TO J
200  READ B(H)
210  NEXT
220  FOR H = 1 TO J
230  READ Q(H)
240  NEXT
250  PRINT " 2. ASSET CHARACTERISTICS": PRINT " "
251  PRINT "    ASSET/                           KILL                KILL              K
     LL"
253  PRINT "    ZONE         NUMBER          PRIORITY            CRITERIA          O
     JECTIVES"
257  FOR T = 1 TO I
258  PRINT "      ";U$(T),"  ";A(T),R(T),Y(T),O(T)
```

```
260  NEXT
262  PRINT " "
264  PRINT " 3. THREAT CHARACTERISTICS": PRINT " "
267  PRINT "   REENTRY                          RELIABILITY/ "
269  PRINT "   VEHICLE        NUMBER       AVAILABILITY"
275  FOR H = 1 TO J
277  PRINT "        ";H,"  ";B(H),Q(H)
279  NEXT
282  PRINT " "
285  PRINT " 4. INTERCEPTOR CHARACTERISTICS": PRINT " "
287  PRINT "                        NUMBER OF"
290  PRINT "    ASSET/        INTERCEPTORS    PROBABILITY OF"
291  PRINT "    ZONE            PER ASSET        INTERCEPT"
292  FOR T = 1 TO I
294  PRINT "       ";U$(T),"       ";NN(T),"       ";II(T)
298  NEXT
299  PRINT " "
300  REM  STEP TWO
310  FOR T = 1 TO I
320 A(T) =  INT ((A(T) * Q(T)) + .9999)
330  NEXT
340  FOR H = 1 TO J
345  FOR T = 1 TO I
350 P(T,H) = P(T,H) * Q(H)
355  NEXT
360  NEXT
361  PRINT "OUTPUT:": PRINT " "
365  PRINT "     ASSET/        ASSETS         REENTRY          R.V.'S PER
      TOTAL R.V.'S "
366  PRINT "     ZONE          KILLED         VEHICLE             ASSET
       ALLOCATED"
500  REM   STEP 3-FIND THE HIGHEST PRIORITY
505 W = 1
510 R = 99999
520  FOR T = 1 TO I
530  IF R(T) < R GOTO 550
540  GOTO 560
550 R = R(T):A = T
560  NEXT
580  REM   STEP 4-FIND THE HIGHEST PROBABILITY WITHIN ONE ROW
590 E =   - 99999
600  FOR H = 1 TO J
610  IF P(A,H) > E GOTO 630
620  GOTO 640
630 E = P(A,H):B = H
640  NEXT
650  IF E = 0 GOTO 955
690  REM   STEP 5-START THE ALGORITHM
700 TR = E * (1 - II(A))
710  FOR C = 1 TO 100
715  IF C > NN(A) GOTO 721
716 U = (1 - TR) ^ C
717 X = 1 - U
719 LL = U
```

```
720  GOTO 730
721  IF C = 1 GOTO 723
722  GOTO 724
723 LL = 1
724 U = LL * ((1 - E) ^ (C - NN(A)))
725 X = (1 - U)
730  IF X >  = Y(A) GOTO 760
750  NEXT
760 V = C
770  IF A(A) * V <  = B(B) GOTO 880
780 S = B(B) / V
782 S =  INT (S + .99999999)
783 A(A) = A(A) - S
785 B(B) = B(B) - S * V
787  IF B(B) < 0 THEN  GOTO 790
788  IF S = 0 GOTO 800
789  GOTO 795
790 S = S - 1
791  IF S = 0 GOTO 800
795  PRINT "        ";U$(A);"    ";S;"    ";B;"    ";V;"    ";S * V
800  FOR T = 1 TO I
810 P(T,B) = 0
820  NEXT
825 B(B) = B(B) - S * V
830  GOTO 590
880 B(B) = B(B) - (A(A) * V)
885  IF B(B) < 0 GOTO 890
886  IF A(A) = 0 GOTO 900
887  GOTO 895
890 A(A) = A(A) - 1
891  IF A(A) = 0 GOTO 900
895  PRINT "        ";U$(A);"    ";A(A);"    ";B;"    ";V;"    ";A(A) * V
900  FOR H = 1 TO J
910 P(A,H) = 0
920  NEXT
930 R(A) = 9999
955 W = W + 1: IF W > I GOTO 998
960  GOTO 510
998  END
1970  DATA  0,0,0,0,0,0,0,0,0,0
1980  DATA   0.0,0,0,0,0,0,0,0,0
1990  DATA  1/1,1/2,2/1,2/2,2/3,3/1,3/2,3/3,4/1,4/2
2000  DATA  .7,.30,.5,.65
2010  DATA  .7,.3,.0,.65
2020  DATA .11,.05,.08,.1
2030  DATA .11,.00,.08,.1
2040  DATA .11,.00,.00,.1
2050  DATA .06,.06,.04,.04
2060  DATA .06,.00,.04,.04
2070  DATA .06,.00,.00,.04
2080  DATA .07,.15,.15,.06
2090  DATA .07,.00,.15,.06
3100  DATA  5,10,15,15,15,20,10,5,10,15
```

```
3110  DATA  .99,.99,.9,.9,.9,.9,.9,.9,.9,.9
3120  DATA  1,2,3,4,5,6,7,8,9,10
3130  DATA  .95,.95,.95,.95,.95,.95,.95,.95,.95,.95
3140  DATA  100,500,200,200
3150  DATA  .9,.9,.9,.9
]
```

APPENDIX V

THREAT ALLOCATION
PROGRAM OUTPUT

]RUN

** THREAT ALLOCATION MODEL **

RUN DESCRIPTION:

ORSA/TIMS: NO DEFENSE

INPUTS:

1. KILL PROBABILITIES

	REENTRY VEHICLE			
ASSET/ZONE	1	2	3	4
1/1	.7	.3	.5	.65
1/2	.7	.3	0	.65
2/1	.11	.05	.08	.1
2/2	.11	0	.08	.1
2/3	.11	0	0	.1
3/1	.06	.06	.04	.04
3/2	.06	0	.04	.04
3/3	.06	0	0	.04
4/1	.07	.15	.15	.06
4/2	.07	0	.15	.06

2. ASSET CHARACTERISTICS

ASSET/ ZONE	NUMBER	KILL PRIORITY	KILL CRITERIA	KILL OBJECTIVES
1/1	5	1	.99	.95
1/2	10	2	.99	.95
2/1	15	3	.9	.95
2/2	15	4	.9	.95
2/3	15	5	.9	.95
3/1	20	6	.9	.95
3/2	10	7	.9	.95
3/3	5	8	.9	.95
4/1	10	9	.9	.95
4/2	15	10	.9	.95

3. THREAT CHARACTERISTICS

REENTRY VEHICLE	NUMBER	RELIABILITY/ AVAILABILITY
1	100	.9
2	500	.9
3	200	.9
4	200	.9

4. INTERCEPTOR CHARACTERISTICS

ASSET/ ZONE	NUMBER OF INTERCEPTORS PER ASSET	PROBABILITY OF INTERCEPT
1/1	0	0
1/2	0	0
2/1	0	0
2/2	0	0
2/3	0	0
3/1	0	0
3/2	0	0
3/3	0	0
4/1	0	0
4/2	0	0

OUTPUT:

ASSET/ ZONE	ASSETS KILLED	REENTRY VEHICLE	R.V.'S PER ASSET	TOTAL R.V.' ALLOCATED
1/1	5	1	5	25
1/2	10	1	5	50
2/1	1	1	23	23
2/1	8	4	25	200
2/1	5	3	31	155
2/2	1	3	31	31

]

]RUN

** THREAT ALLOCATION MODEL **

RUN DESCRIPTION:

ORSA/TIMS: DEFENDED

INPUTS:

1. KILL PROBABILITIES

	REENTRY VEHICLE			
ASSET/ZONE	1	2	3	4
1/1	.7	.3	.5	.65
1/2	.7	.3	0	.65
2/1	.11	.05	.08	.1
2/2	.11	0	.08	.1
2/3	.11	0	0	.1
3/1	.06	.06	.04	.04
3/2	.06	0	.04	.04
3/3	.06	0	0	.04
4/1	.07	.15	.15	.06
4/2	.07	0	.15	.06

2. ASSET CHARACTERISTICS

ASSET/ ZONE	NUMBER	KILL PRIORITY	KILL CRITERIA	KILL OBJECTIVES
1/1	5	1	.99	.95
1/2	10	2	.99	.95
2/1	15	3	.9	.95
2/2	15	4	.9	.95
2/3	15	5	.9	.95
3/1	20	6	.9	.95
3/2	10	7	.9	.95
3/3	5	8	.9	.95
4/1	10	9	.9	.95
4/2	15	10	.9	.95

3. THREAT CHARACTERISTICS

REENTRY VEHICLE	NUMBER	RELIABILITY/ AVAILABILITY
1	100	.9
2	500	.9
3	200	.9
4	200	.9

4. INTERCEPTOR CHARACTERISTICS

ASSET/ ZONE	NUMBER OF INTERCEPTORS PER ASSET	PROBABILITY OF INTERCEPT
1/1	1	.9
1/2	1	.9
2/1	1	.9
2/2	1	.9
2/3	1	.9
3/1	1	.9
3/2	1	.9
3/3	1	.9
4/1	1	.9
4/2	1	.9

OUTPUT:

ASSET/ ZONE	ASSETS KILLED	REENTRY VEHICLE	R.V.'S PER ASSET	TOTAL R.V ALLOCATE
1/1	5	1	6	30
1/2	10	1	6	60
2/1	7	4	26	182
2/1	6	3	32	192

]

APPENDIX VI

TERMINOLOGY AND NOTATION
USED IN R&D PROJECT PLANNING NETWORK SIMULATION

APPENDIX VI

TERMINOLOGY AND NOTATION USED IN R&D PROJECT PLANNING NETWORK SIMULATION

Notation	Definition
P_1	Probability of an unacceptable problem definition
P_2	Probability of a successful evaluation
P_3	Probability of a washout given that the project has been unsuccessfully evaluated
P_4	Probability of an unacceptable problem definition given that the project has been unsuccessfully evaluated and that it did not washout
P_5	Probability of an unsuccessful prototype development

APPENDIX VII

R&D PROJECT PLANNING NETWORK
SIMULATION LOGIC

APPENDIX VII

R&D PROJECT PLANNING NETWORK SIMULATION LOGIC

1. Generate five projects (Block 1) and number them sequentially (Block 2).

2. Place the projects in a queue (Block 3) and set X$FLAG = 1 (Block 4) which acts as a flag that allows a project to start if its value is not equal to zero.

3. Test whether X$FLAG = 0 (Block 5); if yes then place the next project in a wait file (Block 6) and increment time (Block 7) until X$FLAG ≠ 0.

4. Subtract 1 from the value of X$FLAG (Block 8) and select the next project in the queue (Block 9).

5. Read the mean processing time and modifier for stage 1 (Block 10) which is the problem definition stage.

6. Start stage 1 activity (Block 11) and increment time by one day (Block 12) until the duration of stage 1 activity equals V$ACT.TIME which is the random number that was selected from an exponential distribution with the mean and modifier assigned in step 5.

7. Select a random number. If the number selected is less than P_1 then go to step 5, otherwise go to step 8.

8. Read the mean processing time and modifier for stage 2 (Block 15) which is the Research Activity Stage.

APPENDIX VII

(CONTINUED)

9. Start stage 2 activity (Block 16) and increment time by one day (Block 17) until the duration of stage 2 activity equals V$ACT.TIME which is the random number that was selected from an exponential distribution with the mean and modifier assigned in step 8.

10. Read the mean processing time and modifier for stage 3 (Block 19) which is the solution proposal stage.

11. Start stage 3 activity (Block 20) and increment time by one day (Block 21) until the duration of stage 3 activity equals V$ACT.TIME which is the random number that was selected from an exponential distribution with the mean and modifier assigned in step 10.

12. Select a random number. If the number selected is less than P_2 go to step 16, otherwise go to step 13.

13. Select a random number. If the number selected is less than P_3 go to step 14, otherwise go to step 15.

14. Collect statistics for the duration of a project washout and check to see if that was the last project in the R&D network (i.e., project 5). If it is project number 5 then terminate the network, otherwise start a new project by incrementing X$FLAG by one and go to step 3 (Blocks 25-28).

APPENDIX VII

(CONTINUED)

15. Select a random number. If the number selected is less than P_4 go to step 5, otherwise go to step 8.

16. Read the mean processing time and modifier for stage 4 (Block 30) which is the prototype development stage.

17. Start stage 4 activity (Block 31) and increment time by one day (Block 32) until the duration of stage 4 activity equals V$ACT.TIME which is the random number that was selected from an exponential distribution with the mean and modifier assigned in step 16.

18. Read the mean processing time and modifier for stage 5 (Block 34) which is the solution implementation stage.

19. Start stage 5 activity (Block 35) and increment time by one day (Block 36) until the duration of stage 5 activity equals V$ACT.TIME which is the random number that was selected from an exponential distribution with the mean and modifier assigned in step 18.

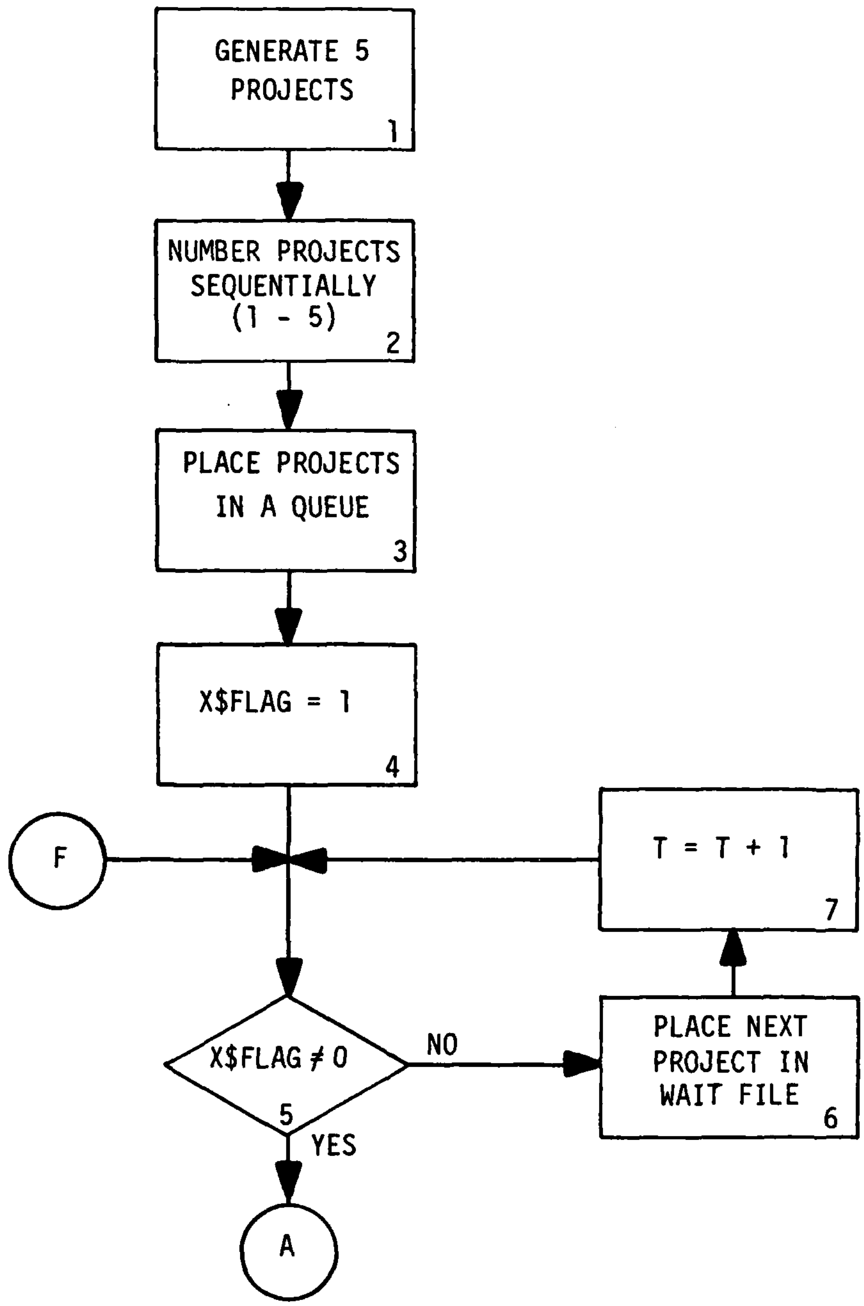
20. Check to see if the project completed was the last project in the R&D network (i.e., project 5). If it is project number 5 then collect statistics for the duration of the 5th project successful completion and terminate the network, otherwise collect statistics, start a new project by incrementing X$FLAG by one and go to step 3 (Blocks 38-42).

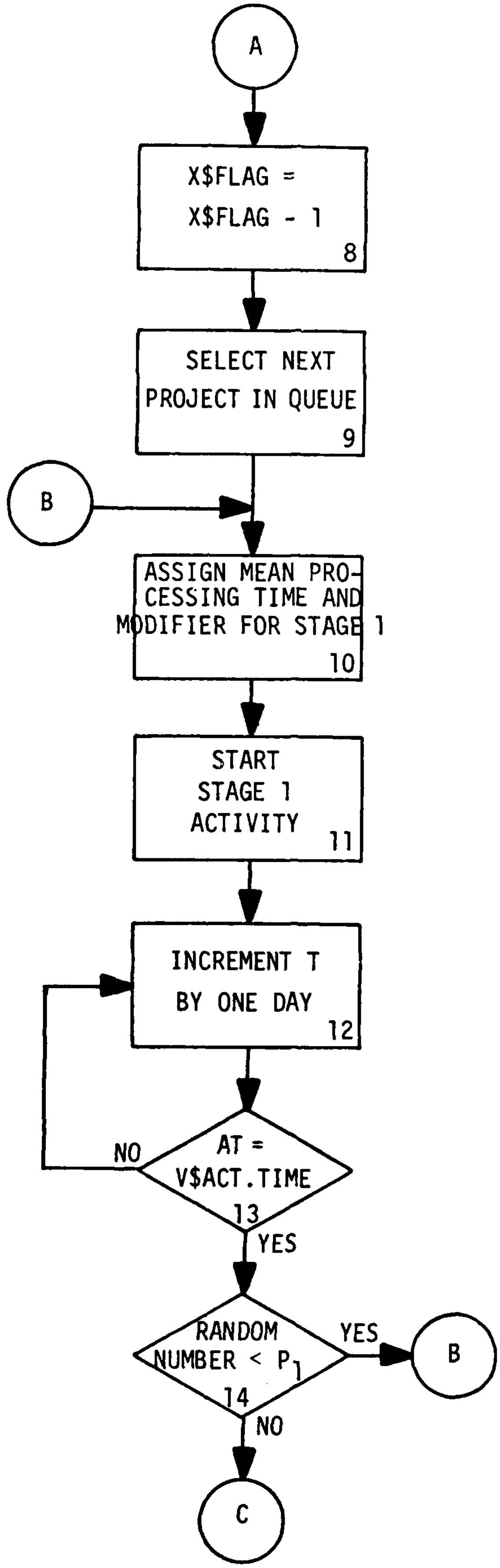
APPENDIX VIII

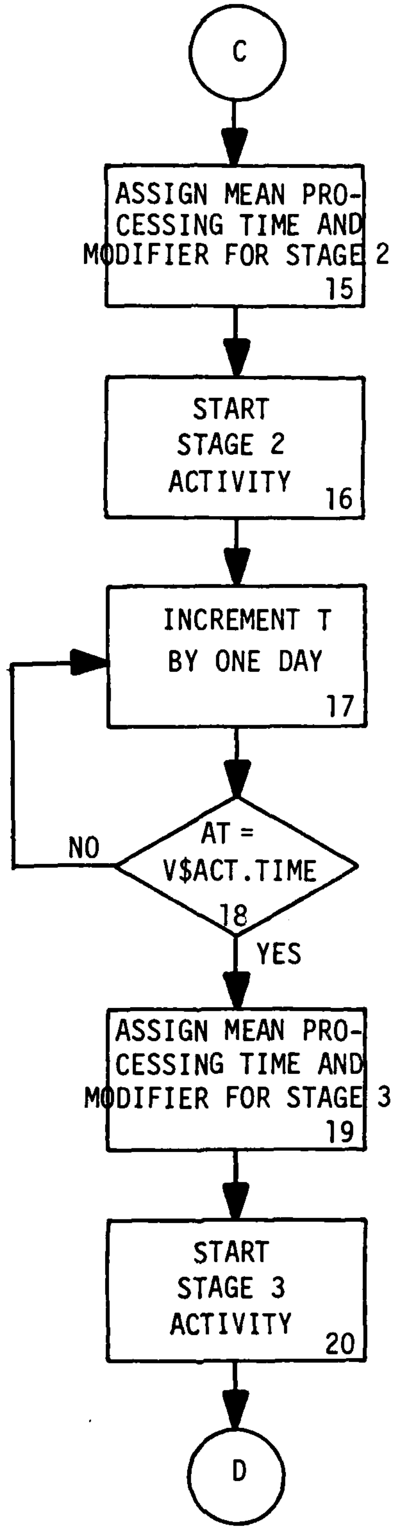
R&D PROJECT PLANNING NETWORK
SIMULATION MODEL FLOWCHART

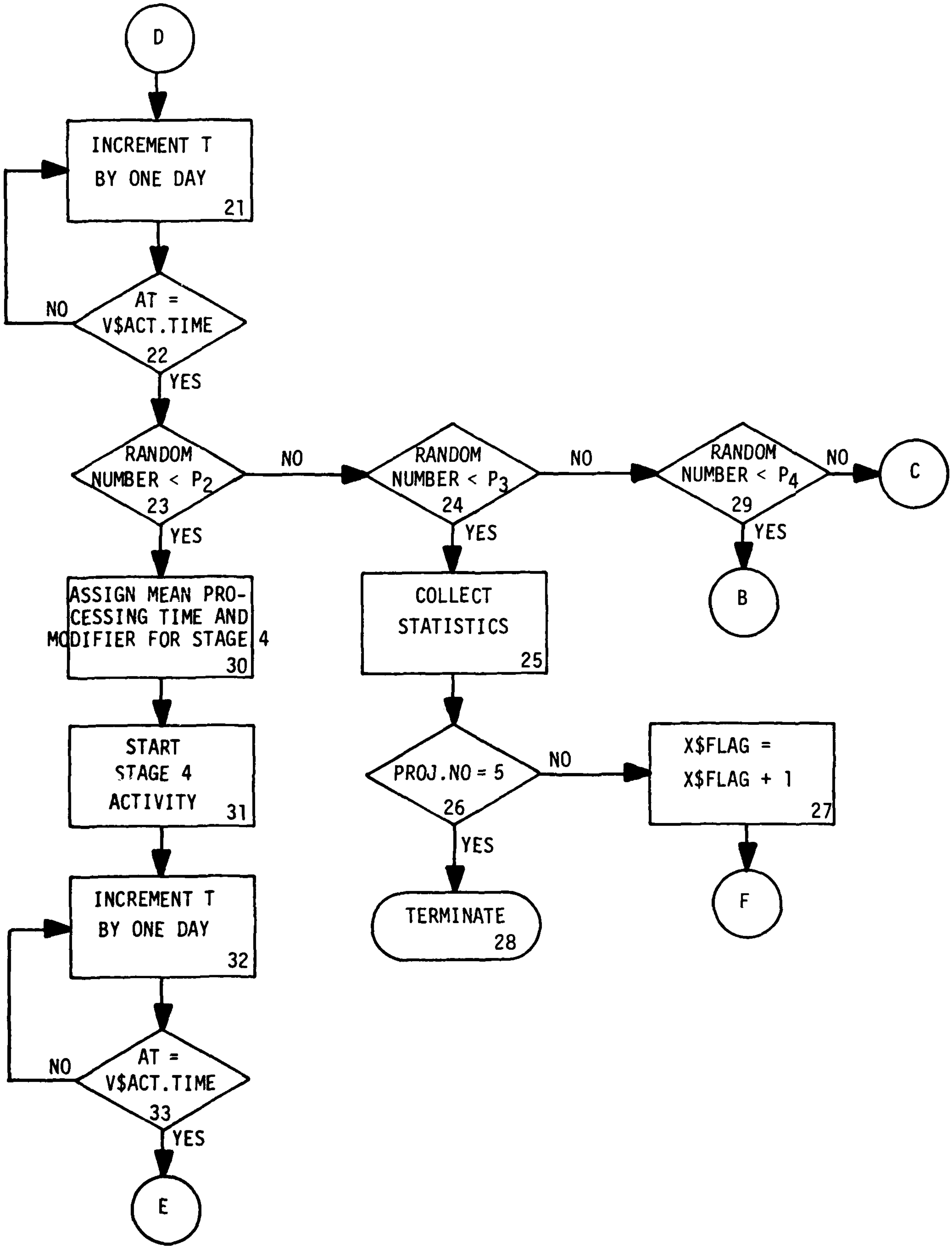
APPENDIX VIII

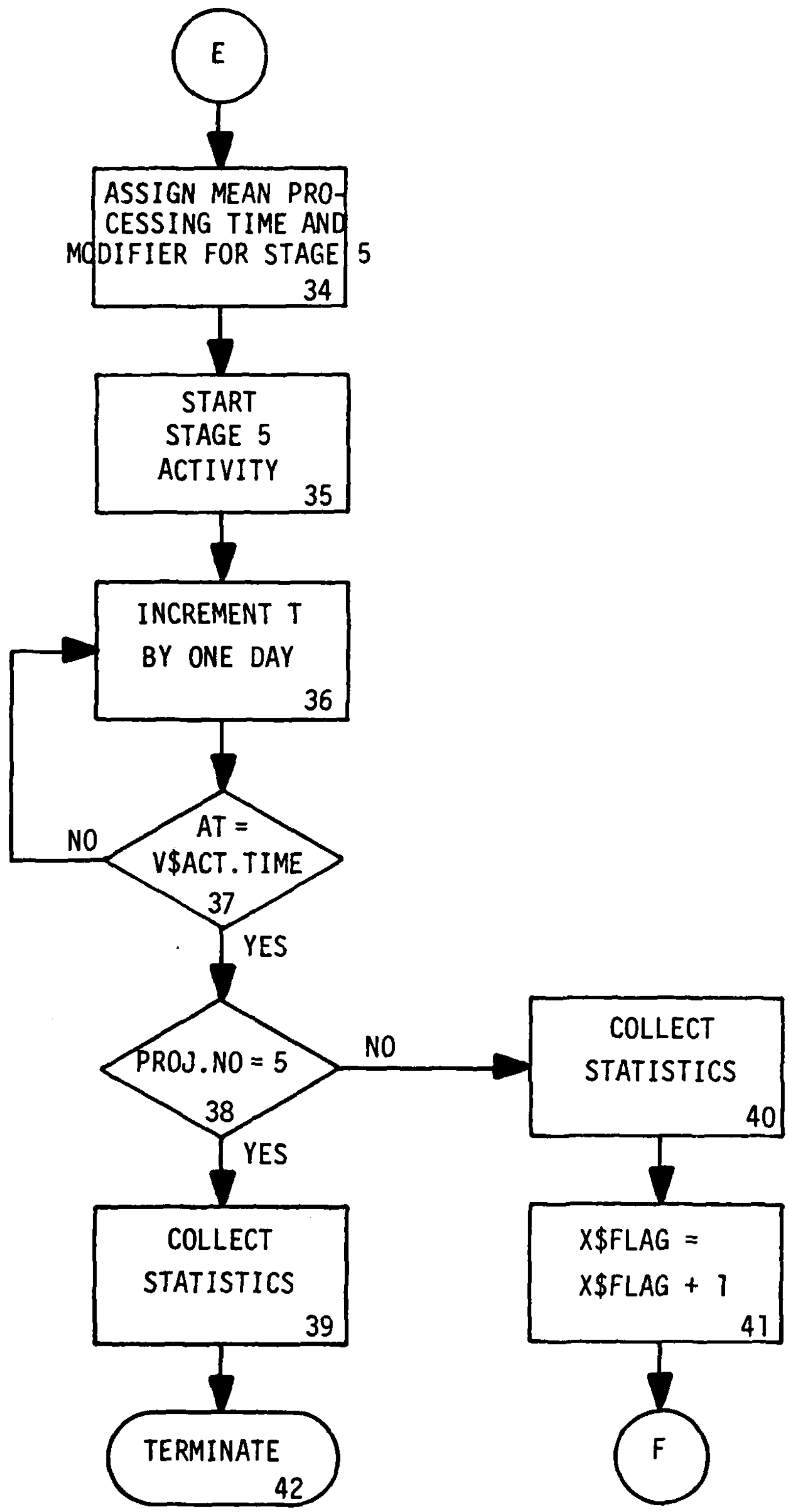
R&D PROJECT PLANNING NETWORK
SIMULATION MODEL FLOWCHART




A
X$FLAG =
X$FLAG - 1
8
SELECT NEXT
PROJECT IN QUEUE
9
B
ASSIGN MEAN PROCESSING TIME AND MODIFIER FOR STAGE 1
10
START
STAGE 1
ACTIVITY
11
INCREMENT T
BY ONE DAY
12
NO
AT =
V$ACT.TIME
13
YES
RANDOM
NUMBER < P1
14
YES
B
NO
C


C
ASSIGN MEAN PROCESSING TIME AND MODIFIER FOR STAGE 2
15
START STAGE 2 ACTIVITY
16
INCREMENT T BY ONE DAY
17
AT = V$ACT.TIME
18
NO
YES
ASSIGN MEAN PROCESSING TIME AND MODIFIER FOR STAGE 3
19
START STAGE 3 ACTIVITY
20
D


D
INCREMENT T BY ONE DAY 21
NO
AT = V$ACT.TIME 22
YES
RANDOM NUMBER < P2 23
NO
RANDOM NUMBER < P3 24
NO
RANDOM NUMBER < P4 29
NO
C
YES
B
YES
ASSIGN MEAN PROCESSING TIME AND MODIFIER FOR STAGE 4 30
YES
COLLECT STATISTICS 25
START STAGE 4 ACTIVITY 31
PROJ.NO = 5 26
NO
X$FLAG = X$FLAG + 1 27
F
YES
TERMINATE 28
INCREMENT T BY ONE DAY 32
NO
AT = V$ACT.TIME 33
YES
E


E
ASSIGN MEAN PROCESSING TIME AND MODIFIER FOR STAGE 5
34
START STAGE 5 ACTIVITY
35
INCREMENT T BY ONE DAY
36
AT = V$ACT.TIME
37
NO
YES
PROJ.NO = 5
38
NO
YES
COLLECT STATISTICS
40
COLLECT STATISTICS
39
X$FLAG = X$FLAG + 1
41
TERMINATE
42
F

APPENDIX IX

R&D PROJECT PLANNING NETWORK
SIMULATION PROGRAM LISTING

```
QMODL1,A
 GPSS 4.1   -11/20-10:51-(000)

                       JOB
       *
                       ORDER,FN        1
                       ORDER,X         6
                       ORDER,T         40
       SYS.STUDY       CAPACITY        6
       RFP.PREP        CAPACITY        6
       CON.PROP        CAPACITY        6
       EVAL.AWD        CAPACITY        6
       CON.WORK        CAPACITY        6
       CON.EVAL        CAPACITY        6
       *
       *   NETWORK SIMULATOR: MULTIPLE R&D PROJECT
       *
       PROJ.TIME       TABLE           V$PRO.TIME,1400,100,10
       T(1)            TABLE           V$PRO.TIME,500,50,8
       T(2)            TABLE           V$PRO.TIME,500,50,8
       T(3)            TABLE           V$PRO.TIME,500,50,8
       T(4)            TABLE           V$PRO.TIME,1000,70,8
       T(5)            TABLE           V$PRO.TIME,1000,70,8
       T(6)            TABLE           V$PRO.TIME,1500,70,8
       T(31)           TABLE           M$1,100,100,10
       T(32)           TABLE           M$1,100,100,10
       T(33)           TABLE           M$1,100,100,10
       T(34)           TABLE           M$1,100,100,10
       T(35)           TABLE           M$1,100,100,10
       T(36)           TABLE           M$1,100,100,10
       T(21)           TABLE           V$PRO.TIME,500,50,8
       T(22)           TABLE           V$PRO.TIME,500,50,8
       T(23)           TABLE           V$PRO.TIME,500,50,8
       T(24)           TABLE           V$PRO.TIME,1000,70,8
       T(25)           TABLE           V$PRO.TIME,1000,70,8
       T(26)           TABLE           V$PRO.TIME,1500,70,8
       FAIL.STUDY      TABLE           P$PROJ.NO,0,1,7
       FAIL.RFP        TABLE           P$PROJ.NO,0,1,7
       FAIL.WORK       TABLE           P$PROJ.NO,0,1,7
       FAIL.PROJ       TABLE           P$PROJ.NO,0,1,7
       TAB.VAR         VARIABLE        P$PROJ.NO+30
       PRO.TIME        VARIABLE        C$1-X$NET.START
       S.POINT         VARIABLE        P$PROJ.NO+20
       *
       *          MATRIX VAL(I,J) STORES PROJECT DATA AS FOLLOWS:
       *
       *               COL  1:   PROJECT NO.
       *               COL  2:   SYSTEMS STUDY ACTIVITY TIME, MEAN
       *               COL  3:   SYSTEMS STUDY ACTIVITY TIME, MODIFIER
       *               COL  4:   RFP ACTIVITY TIME, MEAN
       *               COL  5:   RFP ACTIVITY TIME, MODIFIER
       *               COL  6:   PROPOSAL DEVELOPMENT ACTIVITY TIME, MEAN
       *               COL  7:   PROPOSAL DEVELOPMENT ACTIVITY TIME, MODIFIER
       *               COL  8:   PROPOSAL EVALUATION ACTIVITY TIME, MEAN
       *               COL  9:   PROPOSAL EVALUATION ACTIVITY TIME, MODIFIER
       *               COL 10:   CONTRACTOR EFFORT ACTIVITY TIME, MEAN
       *               COL 11:   CONTRACTOR EFFORT ACTIVITY TIME, MODIFIER
```

```
        *              COL 12:   EVALUATION ACTIVITY TIME, MEAN
        *              COL 13:   EVALUATION ACTIVITY TIME, MODIFIER
        *              COL 14:   PROBABILITY OF ACCEPTABLE INITIAL DEFINITION
        *              COL 15:   PROBABILITY OF UNACCEPTABLE PROPOSALS
        *              COL 16:   PROBABILITY THAT ADDITIONAL EFFORT IS REQUIRED
        *              COL 17:   PROBABILITY THAT SOLUTION IS UNACCEPTABLE
        *              COL 18:   NUMBER OF DIRECT PRECEDENT PROJECTS
        *              COL 19:   NUMBER OF DIRECT ANTECEDENT PROJECTS
        *              COL 20-25: PROJECT NUMBERS OF ANTECEDENT PROJECTS
        *
                       MATRIX         VAL(6,25)
                       INITIAL        VAL(1,1-11),1,84,1,32,1,58,0,24,0,360,0
                       INITIAL        VAL(1,12-20),63,1,925,005,014,065,0,1,4
                       INITIAL        VAL(2,1-11),2,92,1,31,1,68,0,35,0,348,0
                       INITIAL        VAL(2,12-21),52,1,945,020,050,010,0,2,4,5
                       INITIAL        VAL(3,1-11),3,95,1,26,1,53,0,33,0,380,0
                       INITIAL        VAL(3,12-20),61,1,999,070,038,070,0,1,5
                       INITIAL        VAL(4,1-11),4,80,1,24,1,62,0,26,0,325,0
                       INITIAL        VAL(4,12-20),57,1,900,050,045,030,2,1,6
                       INITIAL        VAL(5,1-11),5,85,1,20,1,49,0,39,0,392,0
                       INITIAL        VAL(5,12-20),47,1,972,020,004,055,2,1,6
                       INITIAL        VAL(6,1-11),6,99,1,22,1,67,0,35,0,358,0
                       INITIAL        VAL(6,12-19),69,1,942,002,070,024,2,0
                       MATRIX         FAIL.DATA(6,4)
        *
        *          EXPONENTIAL FUNCTION F(1) USED TO MODIFY ACTIVITY TIMES
         FN(1)         FUNCTION,EXP   RF$2,1,1
        *
        *          R&D PROJECT NETWORK
   1                   GENERATE       0,1
   2 PROJ.START        ADVANCE
   3                   SAVEX          NET.START,C$1
   4                   SPLIT          5
   5 TIME.ADJ          ADVANCE
   6                   ASSIGN         PROJ.NO,V$NO.PROJ
     NO.PROJ           VARIABLE       (N$TIME.ADJ-1)//6+1
   7                   ADVANCE        GOTO(PRED.1,INITIAL.)
   8 PRED.1            COMPARE        MX$VAL(P$PROJ.NO,18) NE 0
   9                   COMPARE        X$*PROJ.NO E MX$VAL(P$PROJ.NO,18)
  10                   ASSIGN         POINT.START,V$S.POINT
  11                   TABULATE       *POINT.START
        *            SYSTEM STUDY
  12 INITIAL.          MARK
  13                   ASSIGN         PROJ.SET,C$1
  14 STUDY.1           ASSIGN         PROC.TIME,MX$VAL(P$PROJ.NO,2)
  15                   ASSIGN         PROC.MOD,MX$VAL(P$PROJ.NO,3)
  16                   STORE          SYS.STUDY TIME(V$ACT.TIME)
     ACT.TIME          VARIABLE       P$PROC.TIME+(FN$*PROC.MOD)
  17                   ADVANCE        GOTO(MX$VAL(P$PROJ.NO,14):STUDY.2,RFP.1)
  18 STUDY.2           SAVEX          RE.STUDY,X$RE.STUDY+1
                       MSAVEX         FAIL.DATA(P$PROJ.NO,1),MX$FAIL.DATA(P$PROJ.
  19 *NO,1)+1
  20                   ADVANCE        GOTO(STUDY.1)
        *            RFP PREPARATION
  21 RFP.1             ASSIGN         PROC.TIME,MX$VAL(P$PROJ.NO,4)
  22                   ASSIGN         PROC.MOD,MX$VAL(P$PROJ.NO,5)
  23                   STORE          RFP.PREP TIME(V$ACT.TIME)
```

```
      *              CONTRACTOR PROPOSAL PREPARATION
 24                     ASSIGN          PROC.TIME,MX$VAL(P$PROJ.NO,6)
 25                     STORE           CON.PROP TIME(P$PROC.TIME)
      *              PROPOSAL EVALUATION AND AWARD
 26                     ASSIGN          PROC.TIME,MX$VAL(P$PROJ.NO,8)
 27                     STORE           EVAL.AWD TIME(P$PROC.TIME)
 28                     ADVANCE         GOTO(MX$VAL(P$PROJ.NO,15):CON.1,RFP.2)
 29 RFP.2               SAVEX           RE.RFP,X$RE.RFP+1
                        MSAVEX          FAIL.DATA(P$PROJ.NO,2),MX$FAIL.DATA(P$PROJ.
 30 +NO,2)+1
 31                     ADVANCE         GOTO(RFP.1)
      *              CONTRACTOR ACTIVITY
 32 CON.1               ASSIGN          PROC.TIME,MX$VAL(P$PROJ.NO,10)
 33                     STORE           CON.WORK TIME(P$PROC.TIME)
      *              CONTRACT EVALUATION
 34                     ASSIGN          PROC.TIME,MX$VAL(P$PROJ.NO,12)
 35                     ASSIGN          PROC.MOD,MX$VAL(P$PROJ.NO,13)
 36                     STORE           CON.EVAL TIME(V$ACT.TIME)
 37                     ADVANCE         GOTO(MX$VAL(P$PROJ.NO,16):EVAL.1,CON.2)
 38 CON.2               SAVEX           RE.WORK,X$RE.WORK+1
                        MSAVEX          FAIL.DATA(P$PROJ.NO,3),MX$FAIL.DATA(P$PROJ.
 39 +NO,3)+1
 40                     ADVANCE         GOTO(CON.1)
 41 EVAL.1              ADVANCE         GOTO(MX$VAL(P$PROJ.NO,17):EVAL.3,EVAL.2)
 42 EVAL.2              SAVEX           PROJ.FAIL,X$PROJ.FAIL+1
                        MSAVEX          FAIL.DATA(P$PROJ.NO,4),MX$FAIL.DATA(P$PROJ.
 43 +NO,4)+1
 44                     ADVANCE         GOTO(STUDY.1)
 45 EVAL.3              ADVANCE         GOTO(NEXT.PROJ,LAST.PROJ)
 46 NEXT.PROJ           COMPARE         MX$VAL(P$PROJ.NO,19) NE 0
 47                     ASSIGN          NO.PROJS,MX$VAL(P$PROJ.NO,19)
 48                     ASSIGN          COL.NO,19
 49 LOOP.START          ASSIGN          COL.NO,P$COL.NO+1
 50                     ASSIGN          PROJ.NEXT,MX$VAL(P$PROJ.NO,P$COL.NO)
 51                     SAVEX           *PROJ.NEXT,X$*PROJ.NEXT+1
 52                     LOOP            NO.PROJS,LOOP.START
 53                     TABULATE        *PROJ.NO
 54                     ASSIGN          PROJ.DUR,V$TAB.VAR
 55                     ASSIGN          PROJ.END,C$1
 56                     TABULATE        *PROJ.DUR
 57                     TERMINATE
 58 LAST.PROJ           TABULATE        PROJ.TIME
 59                     ASSIGN          NO.PROJS,6
 60 START.LOOP          SAVEX           *NO.PROJS,0
 61                     LOOP            NO.PROJS,START.LOOP
 62                     SPLIT           1,PROJ.START
 63                     TABULATE        *PROJ.NO
 64                     ASSIGN          PROJ.DUR,V$TAB.VAR
 65                     ASSIGN          PROJ.END,C$1
 66                     TABULATE        *PROJ.DUR
 67 TERM.CNT            TERMINATE
 68                     GENERATE        0,1
 69                     COMPARE         N$TERM.CNT E 100
 70 COMP.2              ASSIGN          PROJ.NO,P$PROJ.NO+1
 71                     ASSIGN          POINT.START,V$S.POINT
 72                     ASSIGN          PROJ.DUR,V$TAB.VAR
                        HELP            P$PROJ.NO,T9$*POINT.START,TD$*POINT.START,T
```

```
73 +H$*PROJ.DUR,TD$*PROJ.DUR,TB$*PROJ.NO,TD$*PROJ.NO
74                    ADVANCE          GOTO(COMP.1,COMP.2)
75 COMP.1             COMPARE          P$PROJ.NO E 6
76                    ASSIGN           PROJ.NO,0
77 COMP.4             ASSIGN           PROJ.NO,P$PROJ.NO+1
                      HELP             P$PROJ.NO,MX$FAIL.DATA(P$PROJ.NO,1),MX$FAIL
   +.DATA(P$PROJ.NO,2),MX$FAIL.DATA(P$PROJ.NO,3),MX$FAIL.DATA(P$PROJ.NO,4),
78 +,,1
79                    ADVANCE          GOTO(COMP.3,COMP.4)
80 COMP.3             COMPARE          P$PROJ.NO E 6
81                     TERMINATE,R
                       START             1
```

```
STORAGES:
SYS.STUDY      RFP.PREP       CON.PROP       EVAL.AWD       CON.WORK
CON.EVAL

PARAMETERS:
PROJ.NO        POINT.START    PROJ.SET       PROC.TIME      PROC.MOD
NO.PROJS       COL.NO         PROJ.NEXT      PROJ.DUR       PROJ.END

TABLES:
PROJ.TIME      FAIL.STUDY     FAIL.RFP       FAIL.WORK      FAIL.PROJ

SAVEXS:
NET.START      RE.STUDY       RE.RFP         RE.WORK        PROJ.FAIL

MATRIX SAVEXS:
VAL            FAIL.DATA

VARIABLES:
TAB.VAR        PRO.TIME       S.POINT        NO.PROJ        ACT.TIME

BLOCKS:
   2 PROJ.START        5 TIME.ADJ         8 PRED.1
  12 INITIAL.         14 STUDY.1         18 STUDY.2
  21 RFP.1            29 RFP.2           32 CON.1
  38 CON.2            41 EVAL.1          42 EVAL.2
  45 EVAL.3           46 NEXT.PROJ       49 LOOP.START
  58 LAST.PROJ        60 START.LOOP      67 TERM.CNT
  70 COMP.2           75 COMP.1          77 COMP.4
  80 COMP.3

NUMBER OF TRANSACTIONS ALLOWED:  2487
```

NETWORK SIMULATION MODEL
PROGRAM OUTPUT

PROJECT TIMES

PROJECT NUMBER	PROJECT START TIMES MEAN	PROJECT START TIMES STANDARD DEVIATION	PROJECT ACTIVITY TIME MEAN	PROJECT ACTIVITY TIME STANDARD DEVIATION	PROJECT COMPLETION TIME MEAN	PROJECT COMPLETION TIME STANDARD DEVIATION
1	0	0	676	180	676	180
2	0	0	666	149	666	149
3	0	0	705	197	705	197
4	741	178	574	102	1315	200
5	775	199	663	179	1438	252
6	1493	252	674	205	2167	326

FAILURE FREQUENCIES

PROJECT NUMBER	FAILURES PER STAGE: SYSTEM STUDY	REQUEST FOR PROPOSAL	CONTRACTOR ACTIVITY	OVERALL PROJECT
1	7	0	3	8
2	3	3	8	0
3	0	9	3	6
4	12	2	0	1
5	2	2	0	7
6	4	0	9	1

RELATIV, CLOCK TI.,E	ABSOLUTE CLOCK TIME	TERMINATION COUNT
216772	216772	1

BLOCK #	CURR TRAN	TOTAL TRAN	BLOCK #	CURR TRAN	TOTAL TRAN	BLOCK #	CURR TRAN	TOTAL TRAN	BLOCK #	CURR TRAN	TOTAL TRAN	BLOCK #	CURR TRAN	TOTAL TRAN
1	0	1	2	0	100	3	0	100	4	0	100	5	0	600
6	0	600	7	0	600	8	0	300	9	0	300	10	0	300
11	0	300	12	0	600	13	0	600	14	0	651	15	0	651
16	0	651	17	0	651	18	0	28	19	0	28	20	0	28
21	0	639	22	0	639	23	0	639	24	0	639	25	0	639
26	0	639	27	0	639	28	0	639	29	0	16	30	0	16
31	0	16	32	0	646	33	0	646	34	0	646	35	0	646
36	0	646	37	0	646	38	0	23	39	0	23	40	0	23
41	0	623	42	0	23	43	0	23	44	0	23	45	0	600
46	0	500	47	0	500	48	0	500	49	0	600	50	0	600
51	0	600	52	0	600	53	0	500	54	0	500	55	0	500
56	0	500	57	0	500	58	0	100	59	0	100	60	0	600
61	0	600	62	1	100	63	0	100	64	0	100	65	0	100
66	0	100	67	0	100	68	0	1	69	0	1	70	0	6
71	0	6	72	0	6	73	0	6	74	0	6	75	0	1
76	0	1	77	0	6	78	0	6	79	0	6	80	0	1
81	0	1												

SAVEX NAME	SAVFX VALUE	SAVEX NAME	SAVEX VALUE	SAVEX NAME	SAVEX VALUE	SAVEX NAME	SAVEX VALUE
X (1)	0	X (2)	0	X (3)	0	X (4)	0
X (5)	0	X (6)	0	NET.START	214823	RE.STUDY	28
RE.RFP	16	RE.WORK	23	PROJ.FAIL	23		

MATRIX NA.,E: VAL

COLUMN	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20
	21	22	23	24	25					
ROW 1										
	1	84	1	32	1	58	0	24	0	360
	0	63	1	925	5	14	65	0	1	4
	0	0	0	0	0					
ROW 2										
	2	92	1	31	1	68	0	35	0	348
	0	52	1	945	20	50	10	0	2	4
	5	0	0	0	0					
ROW 3										
	3	95	1	26	1	53	0	33	0	380
	0	61	1	999	70	38	70	0	1	5
	0	0	0	0	0					
ROW 4										
	4	80	1	24	1	62	0	26	0	325
	0	57	1	900	50	45	30	2	1	6
	0	0	0	0	0					
ROW 5										
	5	85	1	20	1	49	0	39	0	392
	0	47	1	972	20	4	55	2	1	6
	0	0	0	0	0					
ROW 6										

6	99	1	22	1	67	0	35	0	358
0	69	1	942	2	70	4	2	0	0
0	0	0	0	0					

MATRIX NAME: FAIL.DATA

COLUMN	1	2	3	4
ROW 1	7	0	3	8
ROW 2	3	3	6	0
ROW 3	0	9	3	6
ROW 4	12	2	0	1
ROW 5	2	2	0	7
ROW 6	4	0	9	1

STORAGE NAME	MAXIMUM CONTENTS	AVERAGE CONTENTS	MAXIMUM CAPACITY	AVERAGE CAPACITY	AVERAGE UTILIZATION	TOTAL ENTRIES	TOTAL TRANS	AVERAGE ENT/TRANS	AVERAGE TIME/ENT	CURRENT CONTENTS
SYS.STUDY	3	.24	6	6.00	.0394	651	651	1.00	78.78	0
RFP.PREP	3	.07	6	6.00	.0123	639	639	1.00	25.08	0
CON.PROP	3	.17	6	6.00	.0291	639	639	1.00	59.24	0
EVAL.AWD	3	.09	6	6.00	.0157	639	639	1.00	32.01	0
CON.WORK	3	1.08	6	6.00	.1792	646	646	1.00	360.86	0
CON.EVAL	3	.17	6	6.00	.0286	646	646	1.00	57.68	0

TABLE NAME	NON-WEIGHTED NO. OF ENTRIES	NON-WEIGHTED SUM OF ARGUMENTS	NON-WEIGHTED MEAN ARGUMENT	NON-WEIGHTED STD. DEV.	WEIGHTED NO. OF ENTRIES	WEIGHTED SUM OF ARGUMENTS	WEIGHTED MEAN ARGUMENT	WEIGHTED STD. DEV.
T (1)	100	67638.0000	676.380	180.762	100	67638.0000	676.380	180.762
T (2)	100	66628.0000	666.280	149.377	100	66628.0000	666.280	149.377
T (3)	100	70518.0000	705.180	197.446	100	70518.0000	705.180	197.446
T (4)	100	131580.0000	1315.800	200.250	100	131580.0000	1315.800	200.250
T (5)	100	143869.0000	1438.690	252.573	100	143869.0000	1438.690	252.573
T (6)	100	216772.0000	2167.720	326.547	100	216772.0000	2167.720	326.547
T (7)	0	.0000	.000	.000	0	.0000	.000	.000
T (8)	0	.0000	.000	.000	0	.0000	.000	.000
T (9)	0	.0000	.000	.000	0	.0000	.000	.000
T (10)	0	.0000	.000	.000	0	.0000	.000	.000
T (11)	0	.0000	.000	.000	0	.0000	.000	.000
T (12)	0	.0000	.000	.000	0	.0000	.000	.000
T (13)	0	.0000	.000	.000	0	.0000	.000	.000
T (14)	0	.0000	.000	.000	0	.0000	.000	.000
T (15)	0	.0000	.000	.000	0	.0000	.000	.000
T (16)	0	.0000	.000	.000	0	.0000	.000	.000
T (17)	0	.0000	.000	.000	0	.0000	.000	.000
T (18)	0	.0000	.000	.000	0	.0000	.000	.000
T (19)	0	.0000	.000	.000	0	.0000	.000	.000
T (20)	0	.0000	.000	.000	0	.0000	.000	.000
T (21)	0	.0000	.000	.000	0	.0000	.000	.000
T (22)	0	.0000	.000	.000	0	.0000	.000	.000
T (23)	0	.0000	.000	.000	0	.0000	.000	.000
T (24)	100	74122.0000	741.220	178.076	100	74122.0000	741.220	178.076
T (25)	100	77524.0000	775.240	199.352	100	77524.0000	775.240	199.352
T (26)	100	149357.0000	1493.570	252.950	100	149357.0000	1493.570	252.950
T (27)	0	.0000	.000	.000	0	.0000	.000	.000

T (28)	0	.0000	.000	.000	0	.0000	.000	.000
T (29)	0	.0000	.000	.000	0	.0000	.000	.000
T (30)	0	.0000	.000	.000	0	.0000	.000	.000
T (31)	100	67638.0000	676.380	180.762	100	67638.0000	676.380	180.762
T (32)	100	66628.0000	666.280	149.377	100	66628.0000	666.280	149.377
T (33)	100	70518.0000	705.180	197.446	100	70518.0000	705.180	197.446
T (34)	100	57458.0000	574.580	102.805	100	57458.0000	574.580	102.805
T (35)	100	66345.0000	663.450	179.585	100	66345.0000	663.450	179.585
T (36)	100	67415.0000	674.150	205.232	100	67415.0000	674.150	205.232
T (37)	0	.0000	.000	.000	0	.0000	.000	.000
T (38)	0	.0000	.000	.000	0	.0000	.000	.000
T (39)	0	.0000	.000	.000	0	.0000	.000	.000
T (40)	0	.0000	.000	.000	0	.0000	.000	.000
PROJ.TIME	100	216772.0000	2167.720	326.547	100	216772.0000	2167.720	326.547
FAIL.STUDY	0	.0000	.000	.000	0	.0000	.000	.000
FAIL.RFP	0	.0000	.000	.000	0	.0000	.000	.000
FAIL.WORK	0	.0000	.000	.000	0	.0000	.000	.000
FAIL.PROJ	0	.0000	.000	.000	0	.0000	.000	.000

TABLE NAME: T (1)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
500.0000	5	5.00	5.00	95.00	.739	-.976
550.0000	14	14.00	19.00	81.00	.813	-.699
600.0000	27	27.00	46.00	54.00	.887	-.423
650.0000	13	13.00	59.00	41.00	.961	-.146
700.0000	8	8.00	67.00	33.00	1.035	.131
750.0000	14	14.00	81.00	19.00	1.109	.407
800.0000	4	4.00	85.00	15.00	1.183	.684
850.0000	2	2.00	87.00	13.00	1.257	.960

OVERFLOW OBSERVED FREQUENCY: 13

TABLE NAME: T (2)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
500.0000	2	2.00	2.00	98.00	.750	-1.113
550.0000	18	18.00	20.00	80.00	.825	-.778
600.0000	18	18.00	38.00	62.00	.901	-.444
650.0000	16	16.00	54.00	46.00	.976	-.109
700.0000	17	17.00	71.00	29.00	1.051	.226
750.0000	10	10.00	81.00	19.00	1.126	.560
800.0000	4	4.00	85.00	15.00	1.201	.895
850.0000	5	5.00	90.00	10.00	1.276	1.230

OVERFLOW OBSERVED FREQUENCY: 10

TABLE NAME: T (3)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
500.0000	1	1.00	1.00	99.00	.709	-1.039
550.0000	16	16.00	17.00	83.00	.780	-.786
600.0000	23	23.00	40.00	60.00	.851	-.533
650.0000	15	15.00	55.00	45.00	.922	-.279
700.0000	10	10.00	65.00	35.00	.993	-.026
750.0000	7	7.00	72.00	28.00	1.064	.227

800.0000	7	7.00	79.00	21.00	1.134	.480
850.0000	3	3.00	82.00	18.00	1.205	.733

OVERFLOW OBSERVED FREQUENCY: 18

TABLE NAME : T (4)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000.0000	0	.00	.00	100.00	.760	-1.577
1070.0000	1	1.00	1.00	99.00	.813	-1.227
1140.0000	13	13.00	14.00	86.00	.866	-.878
1210.0000	20	20.00	34.00	66.00	.920	-.528
1280.0000	20	20.00	54.00	46.00	.973	-.179
1350.0000	17	17.00	71.00	29.00	1.026	.171
1420.0000	8	8.00	79.00	21.00	1.079	.520
1490.0000	7	7.00	86.00	14.00	1.132	.870

OVERFLOW OBSERVED FREQUENCY: 14

TABLE NAME : T (5)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000.0000	0	.00	.00	100.00	.695	-1.737
1070.0000	0	.00	.00	100.00	.744	-1.460
1140.0000	5	5.00	5.00	95.00	.792	-1.183
1210.0000	12	12.00	17.00	83.00	.841	-.905
1280.0000	17	17.00	34.00	66.00	.890	-.628
1350.0000	12	12.00	46.00	54.00	.938	-.351
1420.0000	14	14.00	60.00	40.00	.987	-.074
1490.0000	7	7.00	67.00	33.00	1.036	.203

OVERFLOW OBSERVED FREQUENCY: 33

TABLE NAME : T (6)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1500.0000	0	.00	.00	100.00	.692	-2.045
1570.0000	0	.00	.00	100.00	.724	-1.830
1640.0000	0	.00	.00	100.00	.757	-1.616
1710.0000	2	2.00	2.00	98.00	.789	-1.402
1780.0000	7	7.00	9.00	91.00	.821	-1.187
1850.0000	8	8.00	17.00	83.00	.853	-.973
1920.0000	11	11.00	28.00	72.00	.886	-.759
1990.0000	6	6.00	34.00	66.00	.918	-.544

OVERFLOW OBSERVED FREQUENCY: 66

TABLE NAME : T (7)

TABLE NAME : T (8)

TABLE NAME : T (9)

TABLE NAME : T (10)

TABLE NAME : T (11)

TABLE NAME : T (12)

TABLE NAME : T (13)

TABLE NAME : T (14)

TABLE NAME : T (15)

TABLE NAME : T (16)

TABLE NAME : T (17)

TABLE NAME : T (18)

TABLE NAME : T (19)

TABLE NAME : T (20)

TABLE NAME : T (21)

TABLE NAME : T (22)

TABLE NAME : T (23)

TABLE NAME : T (24)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000.0000	91	91.00	91.00	9.00	1.349	1.453
1070.0000	0	.00	91.00	9.00	1.444	1.846
1140.0000	3	3.00	94.00	6.00	1.538	2.239
1210.0000	2	2.00	96.00	4.00	1.632	2.632
1280.0000	2	2.00	98.00	2.00	1.727	3.026
1350.0000	1	1.00	99.00	1.00	1.821	3.419
1420.0000	0	.00	99.00	1.00	1.916	3.812
1490.0000	1	1.00	100.00	.00	2.010	4.205

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NAME : T (25)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000.0000	84	84.00	84.00	16.00	1.290	1.127
1070.0000	5	5.00	89.00	11.00	1.380	1.479
1140.0000	5	5.00	94.00	6.00	1.471	1.830
1210.0000	0	.00	94.00	6.00	1.561	2.181
1280.0000	3	3.00	97.00	3.00	1.651	2.532
1350.0000	2	2.00	99.00	1.00	1.741	2.883
1420.0000	1	1.00	100.00	.00	1.832	3.234

REMAINING FREQUENCIES ARE ALL ZERO

TABLE NAME : T (26)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1500.0000	62	62.00	62.00	38.00	1.004	.025
1570.0000	6	6.00	68.00	32.00	1.051	.302
1640.0000	7	7.00	75.00	25.00	1.098	.579

1710.0000	2	2.00	77.00	23.00	1.145	.856
1780.0000	7	7.00	84.00	16.00	1.192	1.132
1850.0000	5	5.00	89.00	11.00	1.239	1.409
1920.0000	3	3.00	92.00	8.00	1.286	1.686
1990.0000	3	3.00	95.00	5.00	1.332	1.963

OVERFLOW OBSERVED FREQUENCY: 5

TABLE NAME: T (27)

TABLE NAME: T (28)

TABLE NAME: T (29)

TABLE NAME: T (30)

TABLE NAME: T (31)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
100.0000	0	.00	.00	100.00	.148	-3.189
200.0000	0	.00	.00	100.00	.296	-2.635
300.0000	0	.00	.00	100.00	.444	-2.082
400.0000	0	.00	.00	100.00	.591	-1.529
500.0000	5	5.00	5.00	95.00	.739	-.976
600.0000	41	41.00	46.00	54.00	.887	-.423
700.0000	21	21.00	67.00	33.00	1.035	.131
800.0000	18	18.00	85.00	15.00	1.183	.684
900.0000	5	5.00	90.00	10.00	1.331	1.237
1000.0000	2	2.00	92.00	8.00	1.478	1.790

OVERFLOW OBSERVED FREQUENCY: 8

TABLE NAME: T (32)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
100.0000	0	.00	.00	100.00	.150	-3.791
200.0000	0	.00	.00	100.00	.300	-3.121
300.0000	0	.00	.00	100.00	.450	-2.452
400.0000	0	.00	.00	100.00	.600	-1.783
500.0000	2	2.00	2.00	98.00	.750	-1.113
600.0000	36	36.00	38.00	62.00	.901	-.444
700.0000	33	33.00	71.00	29.00	1.051	.226
800.0000	14	14.00	85.00	15.00	1.201	.895
900.0000	9	9.00	94.00	6.00	1.351	1.565
1000.0000	2	2.00	96.00	4.00	1.501	2.234

OVERFLOW OBSERVED FREQUENCY: 4

TABLE NAME: T (33)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
100.0000	0	.00	.00	100.00	.142	-3.065
200.0000	0	.00	.00	100.00	.284	-2.559
300.0000	0	.00	.00	100.00	.425	-2.052
400.0000	0	.00	.00	100.00	.567	-1.546
500.0000	1	1.00	1.00	99.00	.709	-1.039
600.0000	39	39.00	40.00	60.00	.851	-.533

700.0000	25	25.00	65.00	35.00	.993	-.026
800.0000	14	14.00	79.00	21.00	1.134	.480
900.0000	6	6.00	85.00	15.00	1.276	.987
1000.0000	3	3.00	68.00	12.00	1.418	1.493

OVERFLOW OBSERVED FREQUENCY: 12

TABLE NAME: T (34)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
100.0000	0	.00	.00	100.00	.174	-4.616
200.0000	0	.00	.00	100.00	.348	-3.644
300.0000	0	.00	.00	100.00	.522	-2.671
400.0000	0	.00	.00	100.00	.696	-1.698
500.0000	24	24.00	24.00	76.00	.870	-.725
600.0000	44	44.00	68.00	32.00	1.044	.247
700.0000	19	19.00	87.00	13.00	1.218	1.220
800.0000	10	10.00	97.00	3.00	1.392	2.193
900.0000	2	2.00	99.00	1.00	1.566	3.165
1000.0000	0	.00	99.00	1.00	1.740	4.138

OVERFLOW OBSERVED FREQUENCY: 1

TABLE NAME: T (35)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
100.0000	0	.00	.00	100.00	.151	-3.138
200.0000	0	.00	.00	100.00	.301	-2.581
300.0000	0	.00	.00	100.00	.452	-2.024
400.0000	0	.00	.00	100.00	.603	-1.467
500.0000	2	2.00	2.00	98.00	.754	-.910
600.0000	39	39.00	41.00	59.00	.904	-.353
700.0000	36	36.00	77.00	23.00	1.055	.204
800.0000	14	14.00	91.00	9.00	1.206	.760
900.0000	1	1.00	92.00	8.00	1.357	1.317
1000.0000	1	1.00	93.00	7.00	1.507	1.874

OVERFLOW OBSERVED FREQUENCY: 7

TABLE NAME: T (36)

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
100.0000	0	.00	.00	100.00	.148	-2.798
200.0000	0	.00	.00	100.00	.297	-2.310
300.0000	0	.00	.00	100.00	.445	-1.823
400.0000	0	.00	.00	100.00	.593	-1.336
500.0000	3	3.00	3.00	97.00	.742	-.849
600.0000	45	45.00	48.00	52.00	.890	-.361
700.0000	26	26.00	74.00	26.00	1.038	.126
800.0000	8	8.00	82.00	18.00	1.187	.613
900.0000	5	5.00	87.00	13.00	1.335	1.100
1000.0000	4	4.00	91.00	9.00	1.483	1.588

OVERFLOW OBSERVED FREQUENCY: 9

TABLE NAME: T (37)

TABLE NAME: T (38)

TABLE NAME: T (39)

TABLE NAME: T (40)

TABLE NAME: PROJ.TIME

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1400.0000	0	.00	.00	100.00	.646	-2.351
1500.0000	0	.00	.00	100.00	.692	-2.045
1600.0000	0	.00	.00	100.00	.738	-1.739
1700.0000	2	2.00	2.00	98.00	.784	-1.432
1800.0000	9	9.00	11.00	89.00	.830	-1.126
1900.0000	15	15.00	26.00	74.00	.876	-.820
2000.0000	11	11.00	37.00	63.00	.923	-.514
2100.0000	14	14.00	51.00	49.00	.969	-.207
2200.0000	6	6.00	57.00	43.00	1.015	.099
2300.0000	9	9.00	66.00	34.00	1.061	.405

OVERFLOW OBSERVED FREQUENCY: 34

TABLE NAME: FAIL.STUDY

TABLE NAME: FAIL.RFP

TABLE NAME: FAIL.WORK

TABLE NAME: FAIL.PROJ

RANDOM GENERATOR	RANDOM MULTIPLIER	RANDOM INCREMENT	RANDOM SEED
1	1220703125	0	30596069377
2	3141592653	2718281829	16371398781
3	2718281829	3141592653	2718281829
4	10604499373	7261067085	10604499373
5	17249876309	7261067085	17249876309
6	30517578125	7261067085	30517578125
7	2565727293	35981228	2565727293
8	107936437	4292354	107936437
9	22438762221	6891	22438762221
10	621444377	92111326	621444377

APPENDIX X

A THREAT ALLOCATION MODEL
FOR TACTICAL WARFARE

A THREAT ALLOCATION MODEL FOR TACTICAL WARFARE

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A THREAT ALLOCATION MODEL FOR TACTICAL WARFARE

INTRODUCTION

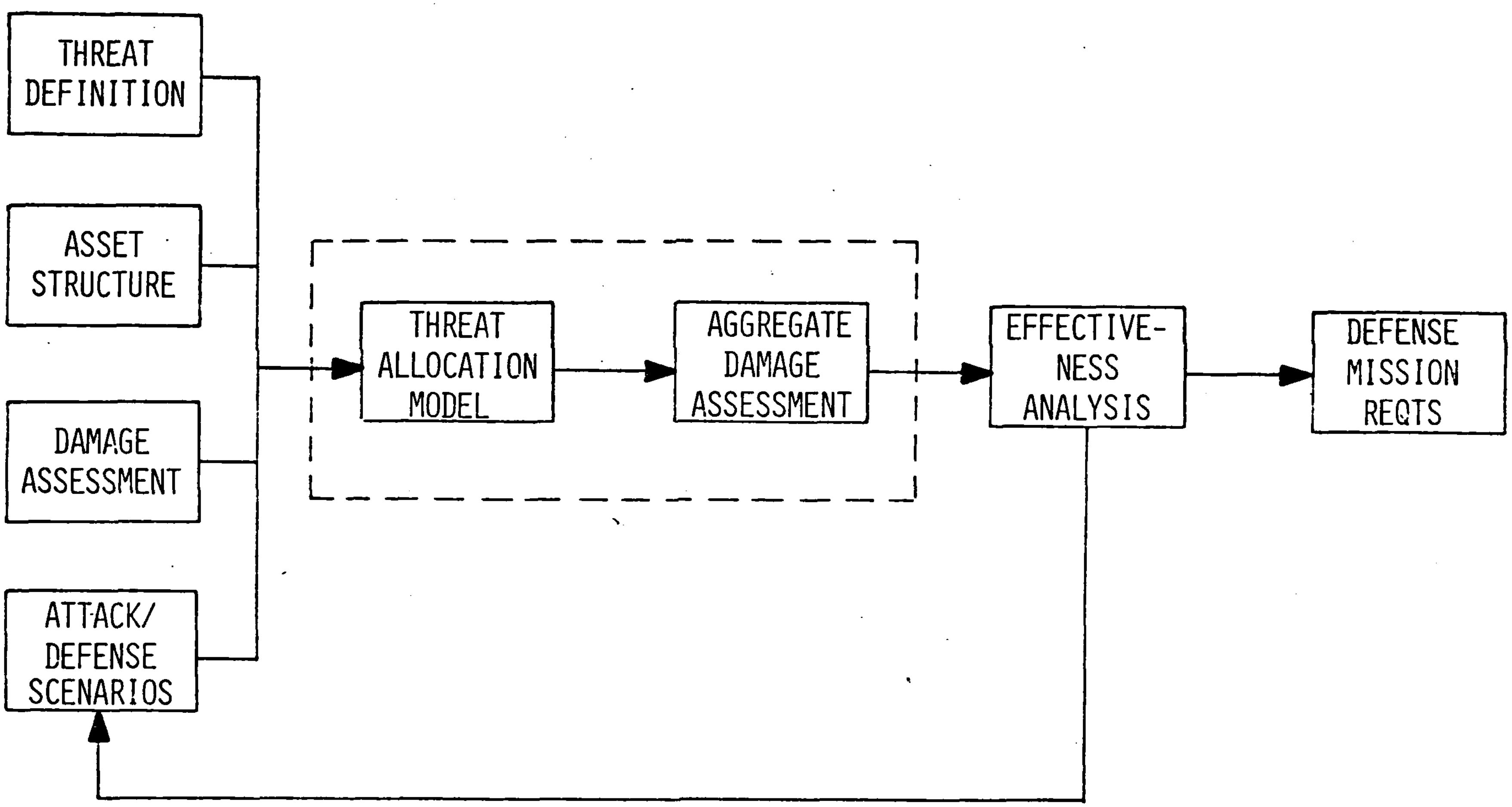
One of the key tasks facing the military planner in specifying defense mission requirements is assessing the nature of the threat which must be countered. In tactical situations, a significant component of the threat may be represented by the opposition's tactical ballistic missile stocks. Thus, a question of extreme importance to the tactical defense system planner is how the opposition might target a given force of tactical ballistic missiles against a specific set of military targets in such a way as to achieve desired military objectives.

The research described in this paper has as its major focus the development of a computer-based mathematical threat allocation model. The research is presented in four parts. The first part details the basic threat allocation decision, identifying and describing important elements of the decision. The mathematical and computer models developed to represent the threat allocation decision are presented in the second part of the paper. Examples of the different types of analysis which are possible with the model are described in the third part. The final part of the paper presents conclusions and identifies areas for future research.

THE THREAT ALLOCATION DECISION

A graphic representation of the mission analysis phase of tactical ballistic missile defense planning is shown in Figure 1. In accomplishing the mission analysis task, the analyst must specify mission requirements necessary to achieve specified military objectives for a given set of military assets for various assumed TBM threats. In order to make such a specification, the analyst must first determine how a specified threat would likely be targeted against the assets and what the resulting damage would be. From Figure 1 it may be seen that the inputs necessary to make threat allocation and damage assessment determinations are: the threat definition, the asset structure, damage assessment, and

Figure 1. TBM Mission Requirements Flow Diagram



attack/defense scenarios. Each of these inputs will now be described as it relates to the allocation decision.

Threat Definition

A TBM threat may be defined by specifying several key characteristics of the threat: (1) the types of TBM's (weapons systems) composing the threat, (2) the types of warheads involved, (3) number and location of launchers, (4) number of boosters, (5) ranges, (6) reload time requirements, and (7) availability/ reliability estimates. An example threat definition based on hypothetical data is shown in Table 1. The threat depicted is composed of four weapons systems identified as RED-1 thru RED-4. The numbers of boosters and ranges (specified in terms of geographic zones) are given for each weapons system. Availability/ reliability estimates are also specified for each weapons system. For purposes of illustration, the number of launchers is assumed to be equal to the number of boosters, hence reload times need not be considered.

Asset Structure

The asset structure against which the TBM threat is targeted is defined in terms of four characteristics: (1) types of assets threatened, (2) number and geographic location (by zone) of each asset, (3) value of each asset, and (4) type of target pattern represented by each asset. An example asset structure based on hypothetical data is shown in Table 2. In the example there are four categories of assets designated as BLUE-1 thru BLUE-4. These categories might represent airbases, missile sites, supply points, command centers or other assets having military significance. Each type of asset is assigned a value from 0 to 1000 which reflects the military importance of that asset type relative to other asset types. Obviously, these values are subjectively determined and will vary depending on military objectives to be achieved. Procedures for assessing the

TABLE 1. THREAT DEFINITION

WEAPONS SYSTEM	NUMBER OF BOOSTERS	RANGE (ZONES)	RELIABILITY/ AVAILABILITY
RED-1	100	1, 2, 3	.9
RED-2	500	1	.9
RED-3	200	1, 2	.9
RED-4	200	1, 2, 3	.9

SOURCE: HYPOTHETICAL DATA.

TABLE 2. ASSET STRUCTURE

ASSET	NUMBER OF ASSETS/ GEOGRAPHIC LOCATION			ASSET VALUE	ASSET TYPE
	ZONE 1	ZONE 2	ZONE 3		
BLUE-1	0	5	10	1,000	C
BLUE-2	15	15	15	500	S
BLUE-3	20	10	5	100	S
BLUE-4	10	15	0	200	S

SOURCE: HYPOTHETICAL DATA.

impact of alternative value schemes are discussed later. Assets are characterized as either simple (S) or complex (C) depending on whether one or more aimpoints must be targeted in order to disable or destroy the asset.

Damage Assessment

The probability of destroying or neutralizing an asset by targeting a single booster on the asset is referred to as a single shot kill probability (P_{SSK}). Table 3 gives hypothetical P_{SSK} values for the assumed threat and asset structure examples described in previous sections. The P_{SSK} values for an actual application are obtained from probability equations or simulation analysis and depend on specified damage criteria required for kill, target position and location error, reentry vehicle lethality, and delivery accuracy.

Attack/Defense Scenarios

In modeling the threat allocation decision, it is necessary to incorporate the capability to treat a variety of military objectives for the threatening force as the objective set is a major determinant in the allocation decision. The allocation model should be flexible enough to permit a broad range of potential objectives represented by specific attack scenarios. Defense scenarios which are inputs to the allocation decision derive from the military objectives of the threatened force and from defensive tactics of interest. Specific attack and defense scenarios which may be addressed are described later in the analysis section of the paper.

In the parlance of decision modeling, the threat definition, the asset structure, damage assessment, and attack scenarios are uncontrollable factors, that is, the decision-maker accepts them as givens even though the values of these factors may be varied for assessment purposes. Defense scenarios are the

TABLE 3. SINGLE SHOT KILL PROBABILITIES

WEAPONS SYSTEM	ASSET			
	BLUE-1	BLUE-2	BLUE-3	BLUE-4
RED-1	.70	.11	.06	.07
RED-2	.30	.05	.06	.15
RED-3	.50	.08	.04	.15
RED-4	.65	.10	.04	.06

SOURCE: HYPOTHETICAL DATA.

decision-maker's choice or controllable factors. The decision-maker is interested in discovering how the assumed threat will be targeted over the assets for attack/defense scenarios of interest. This is the essence of the threat allocation decision.

DECISION FORMULATION

The threat allocation decision described in the preceding section can be formulated in a relatively straightforward manner as a resource allocation decision and treated with conventional resource allocation techniques. The mathematical representation of the threat allocation decision will now be described followed by a discussion of the computer routine that was developed for obtaining allocation schemes.

Mathematical Model

The threat allocation decision is stated mathematically as: determine values for X_{ij} which maximize the function

$$Z = \sum_{j=1}^{n} \sum_{i=1}^{m} F(X_{ij}) \tag{1}$$

Subject to:

$$\sum_{i=1}^{m} X_{ij} \leq A_i \text{ for } j=1, 2, \ldots, n \tag{2}$$

Where

i = the number of TBM weapons systems in the threat, $i=1, 2, \ldots, m$.

A_i = the number of type i boosters available.

j = the number of asset types, $j=1, 2, \ldots, n$.

X_{ij} = the number of type i boosters targeted against each asset of type j.

$F(X_{ij})$ = the expected value of type j assets destroyed by type i TBM's.

The optimization criterion used in making the TBM allocations is the incremental value $\Delta F(X_{ij})$ of type j assets destroyed by an additional booster of type i. For simple assets, those requiring a single aimpoint, the optimization criterion is

$$\Delta F(X_{ij}) = P_{ij} V_j \prod_{i=1}^{m} (1-P_{ij})^{X_{ij}} \tag{3}$$

Where

P_{ij} = the probability of killing a type j asset with a single booster of type i.

V_j = the value of type j assets.

For complex assets, those having physical characteristics which dictate that multiple aimpoints be targeted to neutralize or destroy the asset, the optimization criterion is

$$\Delta F(X_{ij}) = P_{ij} V_j \prod_{i=1}^{m} \left[1 - (1-P_{ij})^{X_{ij}/M}\right]^{M} \tag{4}$$

Where

M = the number of aimpoints which must be targeted.

Equations 1 and 2 constitute a non-linear integer programming model; the objective function for simple assets is a convex function which greatly simplifies the task of obtaining an optimum solution. The procedure used is a modification of the "greedy" algorithm which allocates TBM's to assets one TBM at a time maximizing the incremental value criterion given in equation 3 for each allocation. For complex assets, the objective is not convex, however, a heuristic assignment algorithm was developed which essentially computes the

optimum allocation of TBM's to complex assets by sequential enumeration. Then, if no better allocation to simple assets is possible, the TBM's are allocated to complex assets.

The Computer Model

An interactive FORTRAN program was developed to perform computations necessary to generate optimum threat allocation schemes. The program includes approximately 650 lines of code; execution requires about 70 core blocks of memory and about 30 seconds of CPU time on a UNIVAC 1100/60 time sharing system. Current capacity of the program is 8 TBM types, 300 asset types, and 3 geographic zones. These values may be increased to some extent by judicious alteration of the input data; however, existing capacity is probably adequate to accommodate most situations which might arise.

Decision data required as input is entered either by means of a permanent data file or interactively. Much of the decision data is changed only infrequently during analysis, hence, it is convenient to input and store this data in a permanent file. Some of the data is changed routinely during analysis, so the program was developed to permit interactive input. Required inputs are:

Permanent Data File

- Number of TBM types
- Number of asset types
- Asset values
- Asset locations (number in each zone)
- Kill probabilities

Interactive Inputs

- Availability/Reliability factors
- Number of TBM's

Two types of information are available as output from the threat allocation program: booster-asset allocations and aggregate damage summaries. Booster-asset allocation information is provided in a detailed report for each asset type reflecting the number of boosters of each weapons system allocated to each asset by geographic zone. These reports also reflect damage estimates resulting from the given allocations. An aggregate damage summary shows damage assessments by asset type by zone and total damage and fraction of asset value surviving by asset type. Examples of program output are shown in Figure 2 and 3.

ANALYSIS

The computer-based allocation procedure described in the preceding section offers the defense system planner an extremely flexible tool for analysis. A wide variety of tactical situations can be analyzed with relative ease. To illustrate how the model may be used in analysis, three major types of analysis will be described and illustrated with the threat/asset structure example presented earlier.

Attack Scenarios

One question frequently asked by defense planners relating to various attack scenarios is, what is the impact of changing the TBM stock available to the opposing force? An analysis of the impact of the number of boosters on asset damage is accomplished by generating a series of allocations varying the booster quantities. Figure 4 shows such an analysis in which allocations were made with 20%, 40%, 60%, 80%, 100%, and 120% of the booster quantities given in Table 1. Thus Threat Level in percent of boosters available is the independent variable in Figure 4, while Surviving Fraction of Initial Value of the assets is the dependent variable. The figure shows that for the example situation being considered if 20% of the stock of boosters is targeted against the assets,

FIGURE 2. BOOSTER-ASSET ALLOCATION SUMMARY

TARGET TYPE 2

LABEL : * B-2 ***

MISSILE/WARHEAD		VALUE DESTROYED ZONE 1	ZONE 2	ZONE 3		MISSILES ASSIGNED ZONE 1	ZONE 2	ZONE 3	TOTAL
R-1	NUC	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-1	CHEM	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-1	CONV	.242703	.188199	.188199	******************	40.	30.	30.	100.
R-2	NUC	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-2	CHEM	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-2	CONV	.589419	.000000	.000000	******************	290.	0.	0.	290.
R-3	NUC	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-3	CHEM	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-3	CONV	.311760	.311760	.000000	******************	75.	75.	0.	150.
R-4	NUC	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-4	CHEM	.000000	.000000	.000000	******************	0.	0.	0.	0.
R-4	CONV	.118163	.171900	.171900	******************	20.	30.	30.	80.

TOTALS	1	2	3
VALUE DESTROYED	202.82	174.33	81.94
VALUE	250.00	250.00	250.00
% DESTROYED	.81129076	.53732941	.32774756
TARGETS IN ZONE	15.	15.	15.
AGG VAL DESTROYED	3042.34	2014.98	1229.05

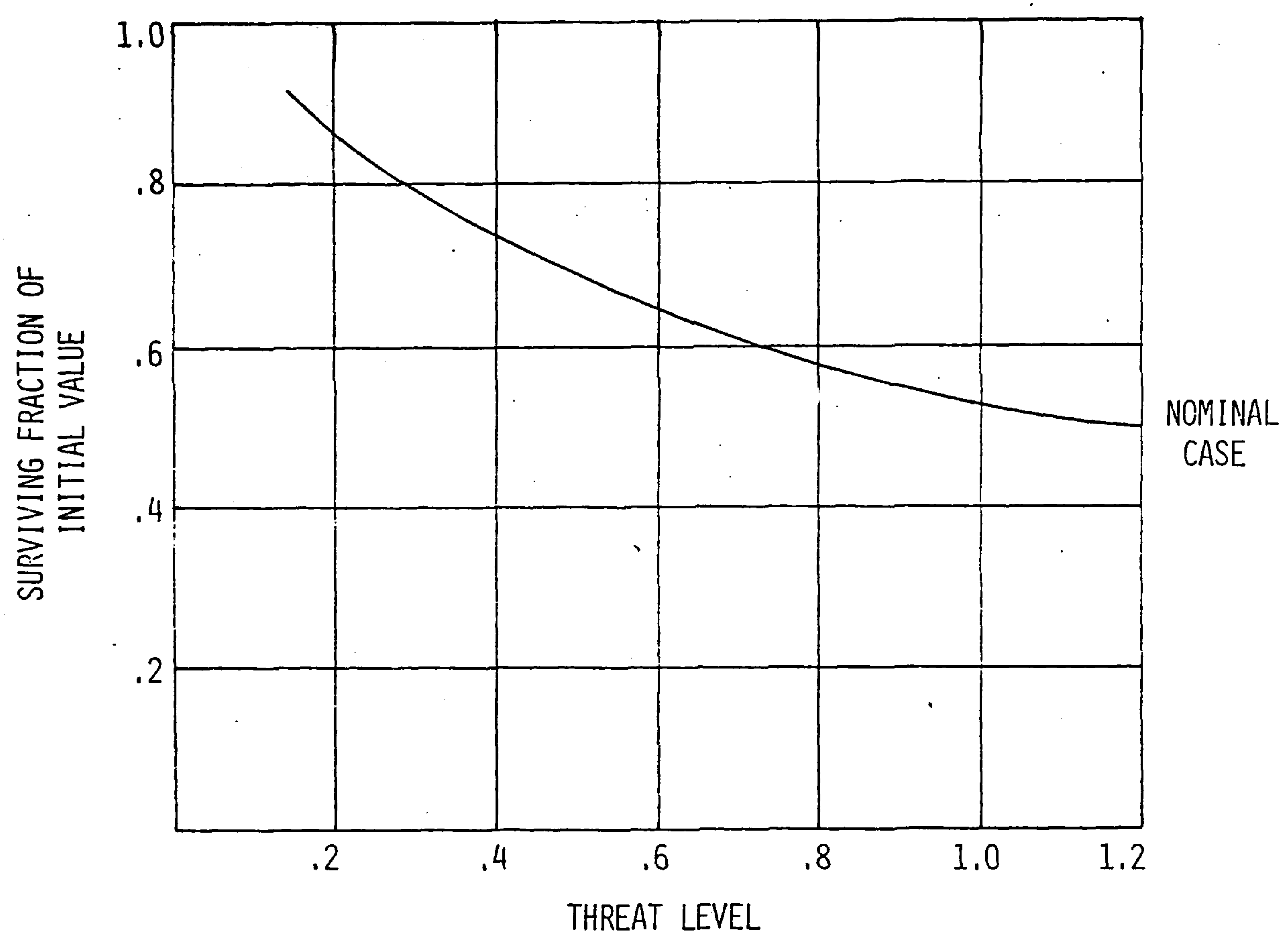
MISSILES USED 620.

FIGURE 3. AGGREGATE DAMAGE SUMMARY

AGGREGATE DAMAGE ASSESSMENT

	ZONE 1	ZONE 2	ZONE 3	TOTAL	SURVIVING
• F-1 •••	.0000	1173.7868	2347.5736	3521.3604	.530485
• F-2 •••	3042.3403	2014.9838	1229.0534	6286.3774	.441211
• F-3 •••	199.1253	.0000	.0000	199.1253	.886214
• F-4 •••	848.2218	574.9931	.0000	1423.2149	.683730
TOTAL	4089.6874	3763.7636	3576.6269	11430.0779	.542797

FIGURE 4. THREAT LEVEL ANALYSIS



approximately 87 percent of the value of the assets would survive; whereas if 120% of the booster stock is targeted, only 50% of the value of assets would survive. Detailed booster-asset allocation schemes and damage summaries for the individual runs depicted in Figure 4 are available from the computer reports.

Parametric Analysis

A variety of "what if" questions may be investigated by performing parametric analysis on individual characteristics of the threat/asset structure system. Figures 5, 6, and 7 show the results of parametric analysis on P_{SSK} values, asset values, and reliability factors respectively; each of these parametric analyses is done in the context of the threat level variation described in the preceding paragraph. Figure 5 indicates that at the 120% threat level, a 20% increase in P_{SSK} values would cause a 10% decrease in the value of assets surviving. Figure 6 shows the impact of changing the value assigned to each of the asset types. The curve labeled "Uniform Values" was generated by assigning a value of 200 to each of the asset types. The figure suggests that the allocation model is relatively insensitive to asset values. Figure 7 presents results of parametric changes on the reliability/availability characteristic of TBM weapons systems.

Defense Scenarios

The model is flexible enough to permit analysis of a variety of defense scenarios. Figure 8 presents results which would be expected from defending the assets against the TBM threat. The curve labeled "Uniform Defense" represents a defense system which would uniformly protect all assets; the curve depicts a system having 60 percent efficiency, that is, only 40 percent of targeted boosters would penetrate the defense. The curve labeled "Preferential Defense" illustrates the impact of protecting "preferred" assets as opposed to uniformly

FIGURE 5. PARAMETRIC ANALYSIS (P_{SSK}).

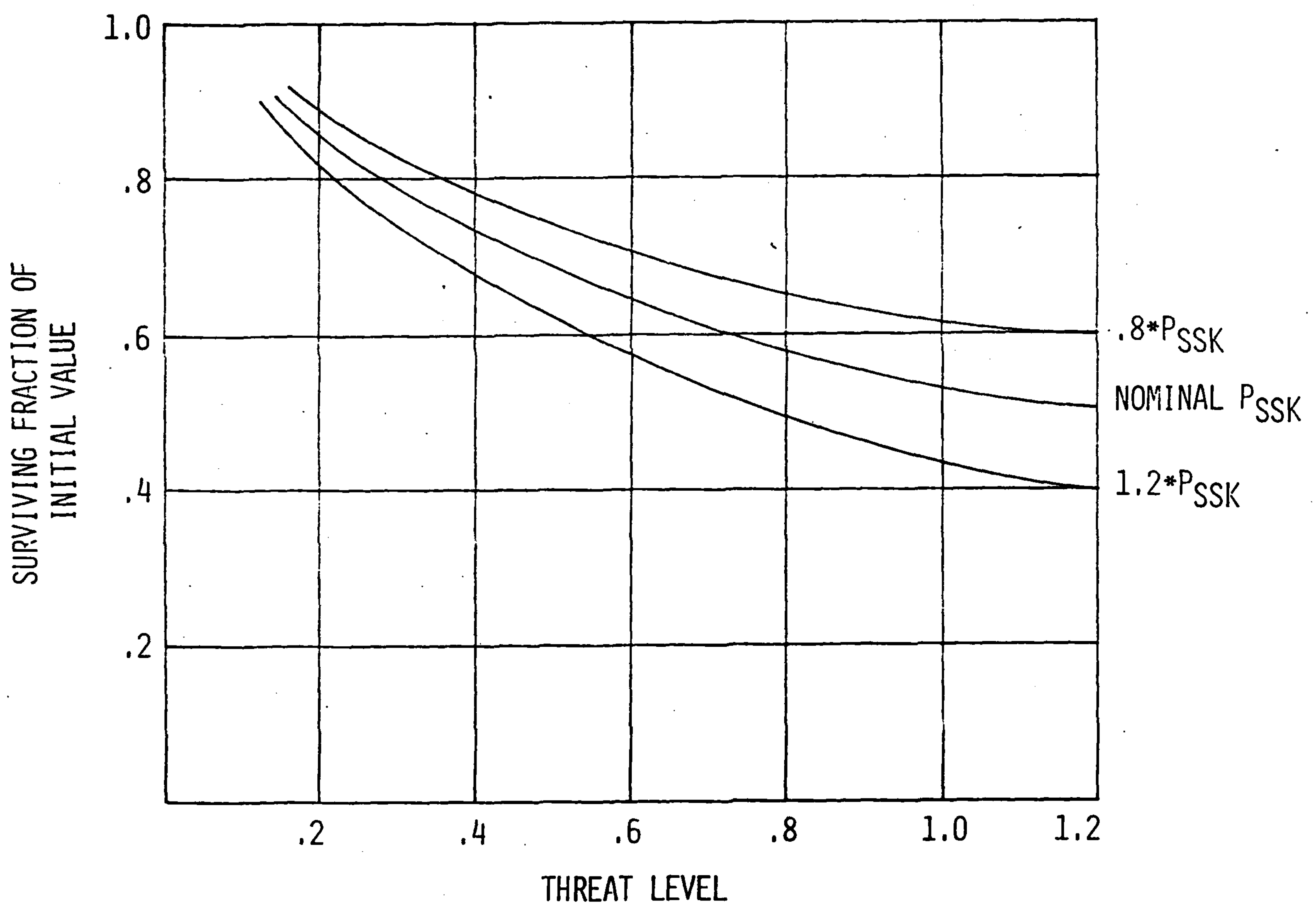


Figure 6. Parametric Analysis (Asset Value).

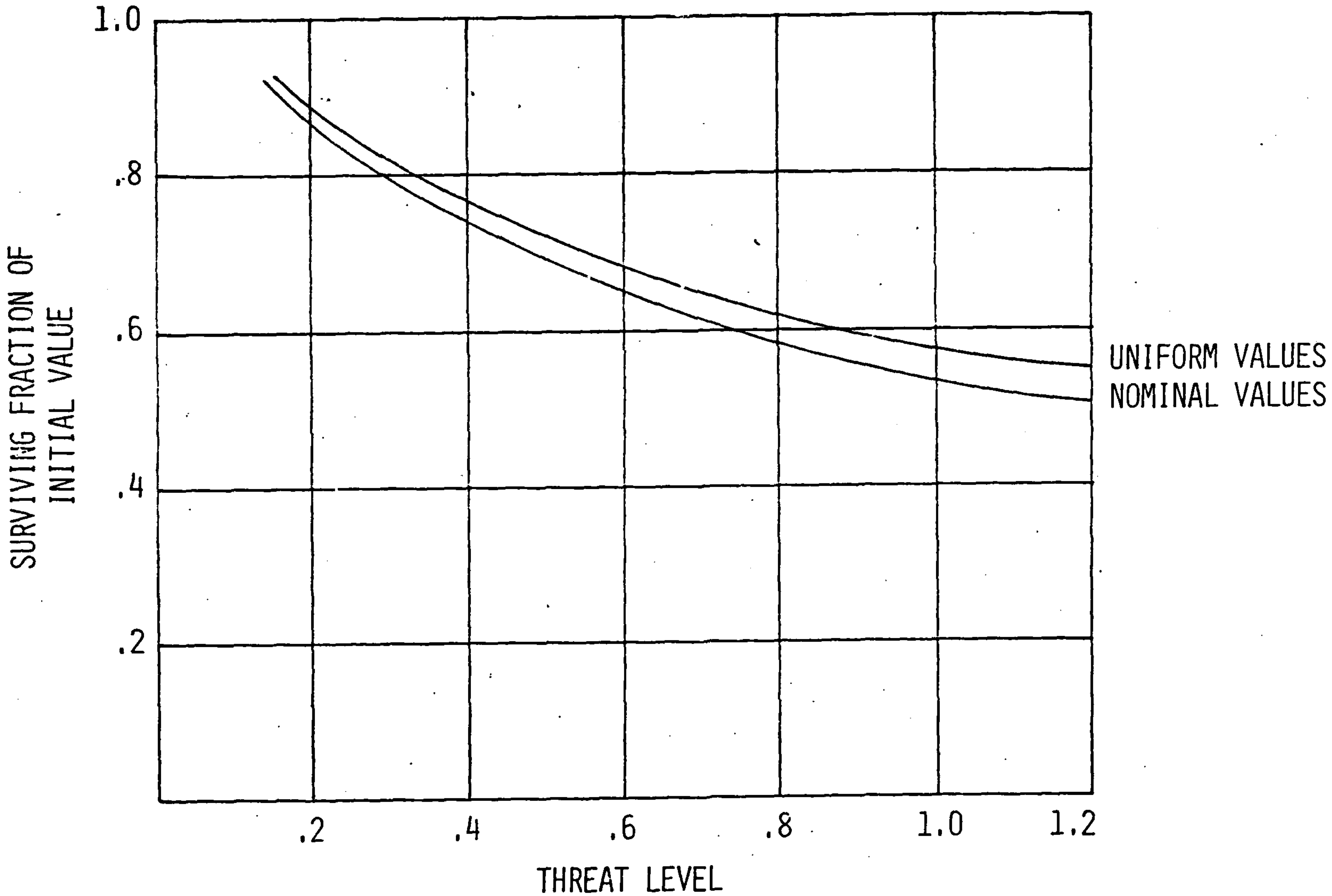


FIGURE 7. PARAMETRIC ANALYSIS (RELIABILITY)

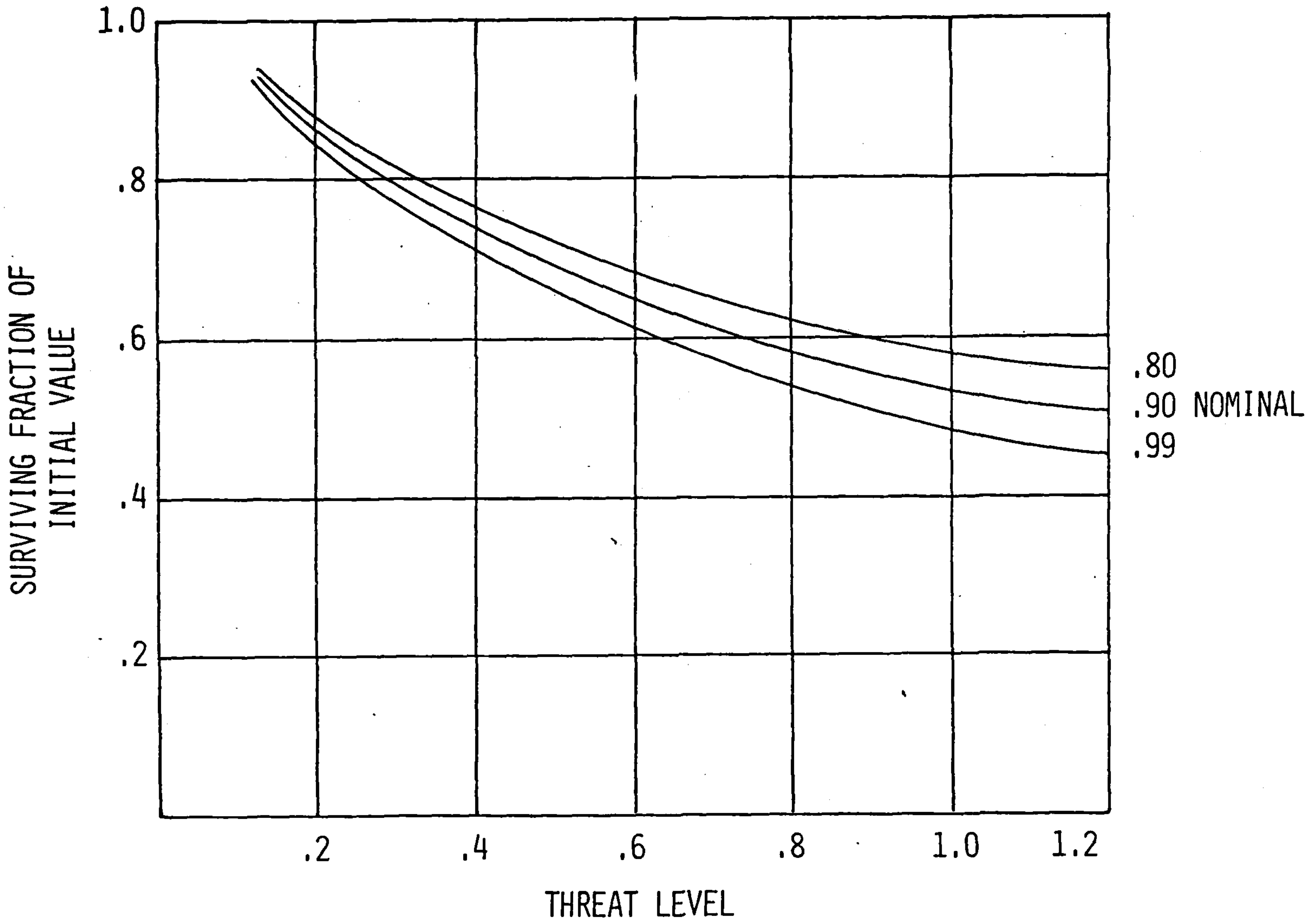
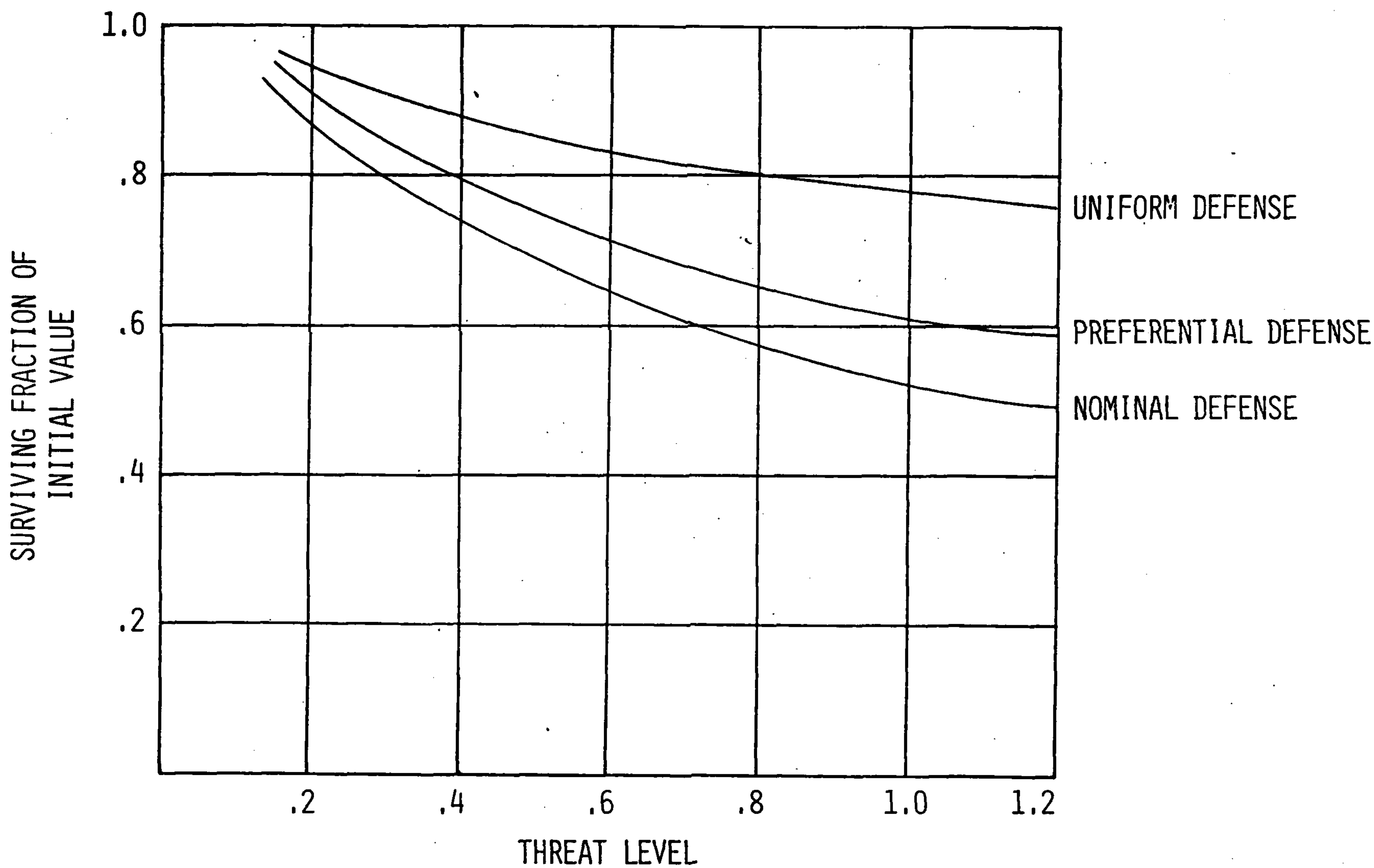


FIGURE 8. DEFENSE SCENARIO ANALYSIS



defending all assets. This curve was generated by reducing the P_{SSK} values for the BLUE-2 asset by 50%, approximating the effect of deploying a defense system for this asset.

The examples presented in this section by no means exhaust the analysis potential of the allocation model; they do serve to illustrate the range and diversity of issues which can be investigated.

CONCLUSIONS

The threat allocation model described in this paper gives the defense system planner an extremely flexible tool for answering the kinds of questions which arise in tactical planning. Data requirements of the model are neither complicated nor elaborate; in fact, most of the input data required would normally be available to a system planner. The model is relatively simple to use and the outputs are largely self-explanatory.

Several revisions of the model have been accomplished in attempting to incorporate as much detail and accuracy as possible and practical. There are a few enhancements and extensions which could further improve the model's usefulness. One possibility for enhancing the model relates to asset valuation; currently assets are valued by subjectively assigning values from 0 to 1000 to each asset type. Presumably, the values assigned reflect the military worth of the asset types. This subjective valuation approach is the most obvious limitation of the model; more objective methods of valuing assets would improve the credibility of the model. With respect to model extensions, the model currently incudes only limited capability for assessing the impacts of threat system logistics, i.e., stockpile quantities, launcher capacities, and resupply and reload times. Clearly, the model's usefulness could be enhanced by incorporating a submodel which described relevant logistics considerations.

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